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

DRAFT Phase II — Recommended Solutions Report

Prepared in Response to the


February 2015

Governor  Secretary for Natural Resources  Director
State of California  The Natural Resources Agency  Department of Water Resources
Bay-Delta Office

Paul A. Marshall................................................................. Chief

South Delta Branch

Mark A. Holderman ......................................................... Branch Chief, South Delta Branch

This report was prepared under the supervision of

Robert Pedlar................................................................. Chief, South Delta Management Section
William McLaughlin ....................................................... Senior Engineer, Water Resources
ACKNOWLEDGEMENTS

The following individuals, agencies, and organizations contributed to the Report.

Key Report Contributors

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>William McLaughlin, P.E.</td>
<td>California Department of Water Resources</td>
</tr>
<tr>
<td>Robert Pedlar, P.E.</td>
<td>California Department of Water Resources</td>
</tr>
<tr>
<td>Khalid Ameri</td>
<td>California Department of Water Resources</td>
</tr>
<tr>
<td>Benjamin Geske</td>
<td>California Department of Water Resources</td>
</tr>
<tr>
<td>Subir Saha, P.E.</td>
<td>California Department of Water Resources</td>
</tr>
<tr>
<td>Jon Burau</td>
<td>U.S. Geological Survey</td>
</tr>
<tr>
<td>Paul Stumpner</td>
<td>U.S. Geological Survey</td>
</tr>
<tr>
<td>Roy Leidy</td>
<td>AECOM</td>
</tr>
<tr>
<td>Sarah Cannon</td>
<td>AECOM</td>
</tr>
<tr>
<td>Cynthia LeDoux-Bloom, Ph.D.</td>
<td>AECOM</td>
</tr>
<tr>
<td>Matt Silva</td>
<td>AECOM</td>
</tr>
<tr>
<td>Steven Pagliughì</td>
<td>AECOM</td>
</tr>
<tr>
<td>Marin Greenwood, Ph.D.</td>
<td>ICF International</td>
</tr>
<tr>
<td>Andy Turnpenny, Ph.D.</td>
<td>Turnpenny Horsfield Associates.</td>
</tr>
</tbody>
</table>

Technical Working Group

Department of Water Resources
- Mark Holderman, P.E.
- Robert Pedlar, P.E.
- Jacob McQuirk, P.E.
- William McLaughlin, P.E.
- Ryan Reeves, P.E.
- Khalid Ameri
- Ben Geske
- Josh Brown

U.S. Bureau of Reclamation
- Josh Israel

California Department of Fish and Wildlife
- George Heise, P.E.
- Daniel Krazville
- Chad Dibble
- Michael Eakin
- Colin Purdy
- Krystal Acierto

National Marine Fisheries Service
- Jeff Stuart
- Steve Thomas, P.E.

U.S. Fish and Wildlife Service
- Maral Kasparian
- Kim Squires
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EXECUTIVE SUMMARY</strong></td>
<td>ES-1</td>
</tr>
<tr>
<td>1 INTRODUCTION</td>
<td>1-1</td>
</tr>
<tr>
<td>1.1 Introduction</td>
<td>1-1</td>
</tr>
<tr>
<td>1.2 Goals and Objectives</td>
<td>1-3</td>
</tr>
<tr>
<td>1.3 Report Organization</td>
<td>1-4</td>
</tr>
<tr>
<td>2 BACKGROUND</td>
<td>2-1</td>
</tr>
<tr>
<td>2.1 Introduction</td>
<td>2-1</td>
</tr>
<tr>
<td>2.2 Summary of Phase I Initial Findings Report</td>
<td>2-3</td>
</tr>
<tr>
<td>3 METHODS</td>
<td>3-1</td>
</tr>
<tr>
<td>3.1 Introduction</td>
<td>3-1</td>
</tr>
<tr>
<td>3.2 Technical Working Group Review Meetings</td>
<td>3-1</td>
</tr>
<tr>
<td>3.3 Field Testing of Engineering Options</td>
<td>3-1</td>
</tr>
<tr>
<td>3.4 Site Environmental Evaluations</td>
<td>3-19</td>
</tr>
<tr>
<td>3.5 Biological Design Considerations</td>
<td>3-19</td>
</tr>
<tr>
<td>3.6 Engineering Design Considerations to Reduce Predation</td>
<td>3-37</td>
</tr>
<tr>
<td>3.7 Recent Related Studies Conducted in the Legal Delta</td>
<td>3-51</td>
</tr>
<tr>
<td>3.8 Water Quality and Flow Modeling</td>
<td>3-60</td>
</tr>
<tr>
<td>3.9 Hydraulic Analysis: Streak-line and Velocity Mapping</td>
<td>3-60</td>
</tr>
<tr>
<td>3.10 Evaluation Framework Including Application of the Water Resource Assessment Methodology</td>
<td>3-60</td>
</tr>
<tr>
<td>4 ENGINEERING EVALUATIONS</td>
<td>4-1</td>
</tr>
<tr>
<td>4.1 Introduction</td>
<td>4-1</td>
</tr>
<tr>
<td>4.2 Engineering Options Removed from Consideration</td>
<td>4-1</td>
</tr>
<tr>
<td>4.3 Criteria Incorporated into Designs</td>
<td>4-2</td>
</tr>
<tr>
<td>4.4 Conceptual-Level Engineering Details</td>
<td>4-3</td>
</tr>
<tr>
<td>5 ENGINEERING EVALUATION RESULTS</td>
<td>5-1</td>
</tr>
<tr>
<td>5.1 Introduction</td>
<td>5-1</td>
</tr>
<tr>
<td>5.2 WRAM Assessments</td>
<td>5-1</td>
</tr>
<tr>
<td>5.3 Options Scoring Summary</td>
<td>5-4</td>
</tr>
<tr>
<td>5.4 Significance of Findings</td>
<td>5-5</td>
</tr>
<tr>
<td>5.5 Engineering Options Integration with Other Studies and Programs</td>
<td>5-6</td>
</tr>
<tr>
<td>6 RECOMMENDATIONS</td>
<td>6-1</td>
</tr>
<tr>
<td>6.1 Introduction</td>
<td>6-1</td>
</tr>
<tr>
<td>6.2 Constraints and Unknowns</td>
<td>6-1</td>
</tr>
<tr>
<td>6.3 Additional Research and Monitoring for Consideration</td>
<td>6-1</td>
</tr>
<tr>
<td>6.4 Ongoing Studies and Analyses</td>
<td>6-2</td>
</tr>
<tr>
<td>6.5 Adaptive Management Implementation</td>
<td>6-2</td>
</tr>
<tr>
<td>7 REFERENCES</td>
<td>7-1</td>
</tr>
</tbody>
</table>
# TABLE OF CONTENTS

## Appendices

| A | Technical Working Group Meeting Summaries |
| B | Conceptual Engineering Design Details |
| C | Environmental Checklists |
| D | Hydrodynamics |
| E | Modeling Physical Barriers |

## Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure ES-1</td>
<td>Action IV.1.3 Study Locations</td>
<td>ES-3</td>
</tr>
<tr>
<td>Figure ES-2</td>
<td>Summary of Options Costs by Locations</td>
<td>ES-7</td>
</tr>
<tr>
<td>Figure 1-1</td>
<td>Map of Delta Study Locations</td>
<td>1-2</td>
</tr>
<tr>
<td>Figure 2-1</td>
<td>Georgiana Slough</td>
<td>2-6</td>
</tr>
<tr>
<td>Figure 2-2</td>
<td>Threemile Slough</td>
<td>2-7</td>
</tr>
<tr>
<td>Figure 2-3</td>
<td>Head of Old River</td>
<td>2-8</td>
</tr>
<tr>
<td>Figure 2-4</td>
<td>Turner Cut</td>
<td>2-10</td>
</tr>
<tr>
<td>Figure 2-5</td>
<td>Columbia Cut</td>
<td>2-11</td>
</tr>
<tr>
<td>Figure 2-6</td>
<td>Red Bluff Pumping Plant and Fish Screen</td>
<td>2-29</td>
</tr>
<tr>
<td>Figure 2-7</td>
<td>Glenn Colusa Irrigation District Fish Screen</td>
<td>2-30</td>
</tr>
<tr>
<td>Figure 2-8</td>
<td>City of Stockton Pumping Facility Fish Screen</td>
<td>2-31</td>
</tr>
<tr>
<td>Figure 2-9</td>
<td>Bottom-Hinged Overflow Gate</td>
<td>2-33</td>
</tr>
<tr>
<td>Figure 2-10</td>
<td>Illustration of an Overflow Gate, Fish Ladder, and Boat Lock located at the Head of Old River</td>
<td>2-34</td>
</tr>
<tr>
<td>Figure 2-11</td>
<td>Schematic Drawing of a Typical Radial Arm Gate System</td>
<td>2-36</td>
</tr>
<tr>
<td>Figure 2-12</td>
<td>Typical Radial Arm Gate</td>
<td>2-36</td>
</tr>
<tr>
<td>Figure 2-13</td>
<td>Vertical Lift Gate with Multiple Panels</td>
<td>2-37</td>
</tr>
<tr>
<td>Figure 2-14</td>
<td>Delta Cross Channel Radial Arm Gates on the Sacramento River</td>
<td>2-38</td>
</tr>
<tr>
<td>Figure 2-15</td>
<td>Aerial View of the Head of Old River Rock Barrier</td>
<td>2-39</td>
</tr>
<tr>
<td>Figure 2-16</td>
<td>Head of Old River Rock Barrier</td>
<td>2-40</td>
</tr>
<tr>
<td>Figure 2-17</td>
<td>Three Sections of a Floating Fish Guidance Structure</td>
<td>2-41</td>
</tr>
<tr>
<td>Figure 2-18</td>
<td>Behavioral Guidance Structure and Trash/Debris Boom at Lower Granite Dam near Colfax, Washington</td>
<td>2-43</td>
</tr>
<tr>
<td>Figure 2-19</td>
<td>Two-Dimensional Trace of a Tagged Juvenile Chinook at the Head of Old River in 2009</td>
<td>2-45</td>
</tr>
<tr>
<td>Figure 2-20</td>
<td>Components of the BAFF System Installed at the Head of Old River</td>
<td>2-46</td>
</tr>
<tr>
<td>Figure 2-21</td>
<td>Two-Dimensional Trace of a Tagged Juvenile Chinook Salmon at the Head of Old River in 2010</td>
<td>2-47</td>
</tr>
<tr>
<td>Figure 2-22</td>
<td>Two-Dimensional Traces of Four Tagged Juvenile Chinook Salmon at Georgiana Slough</td>
<td>2-48</td>
</tr>
<tr>
<td>Figure 2-23</td>
<td>Components of the BAFF System Installed at Georgiana Slough</td>
<td>2-50</td>
</tr>
<tr>
<td>Figure 2-24</td>
<td>Installation of an Electrical Fish Guidance System</td>
<td>2-52</td>
</tr>
<tr>
<td>Figure 2-25</td>
<td>Illustration of a Portable Electrical Fish Guidance System</td>
<td>2-52</td>
</tr>
<tr>
<td>Figure 2-26</td>
<td>Schematic of an Otolith Organ</td>
<td>2-55</td>
</tr>
<tr>
<td>Figure 2-27</td>
<td>Zones of Influence in Particle Acceleration</td>
<td>2-55</td>
</tr>
<tr>
<td>Figure 2-28</td>
<td>Infrasound Fish Fence (left) and Infrasound Generators (right)</td>
<td>2-56</td>
</tr>
<tr>
<td>Figure 3-1</td>
<td>Overview of the 2009 and 2010 Head of Old River Non-Physical Barrier Study Area</td>
<td>3-3</td>
</tr>
<tr>
<td>Figure 3-2</td>
<td>Head of Old River Study Area – 2009 Hydrophone Array and BAFF in Place (red line)</td>
<td>3-4</td>
</tr>
<tr>
<td>Figure 3-3</td>
<td>Head of Old River Study Area – 2010 Hydrophone Array and BAFF in Place (red line)</td>
<td>3-5</td>
</tr>
<tr>
<td>Figure 3-4</td>
<td>Overview of the 2011 and 2012 Georgiana Slough Non-Physical Barrier Study Area</td>
<td>3-10</td>
</tr>
<tr>
<td>Figure 3-5</td>
<td>Study Area Location</td>
<td>3-16</td>
</tr>
</tbody>
</table>
## TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 3-6</td>
<td>FFGS Location</td>
<td>3-17</td>
</tr>
<tr>
<td>Figure 3-7</td>
<td>Preliminary Hydrophone Placement for Monitoring the Georgiana Slough 2014 Physical Barrier (inset) and Surrounding Area</td>
<td>3-18</td>
</tr>
<tr>
<td>Figure 3-8</td>
<td>Detections of Juvenile Chinook Salmon near Georgiana Slough</td>
<td>3-27</td>
</tr>
<tr>
<td>Figure 3-9</td>
<td>Cross-Stream Velocity Vectors</td>
<td>3-28</td>
</tr>
<tr>
<td>Figure 3-10</td>
<td>Juvenile Chinook Expanded Salvage at the Skinner Fish Protection Facility, Byron, California</td>
<td>3-29</td>
</tr>
<tr>
<td>Figure 3-11</td>
<td>Schematic of Components of the Predation Process</td>
<td>3-30</td>
</tr>
<tr>
<td>Figure 3-12</td>
<td>Locations of Stationary Juvenile Salmonid Tags at the Head of Old River, 2009–2012</td>
<td>3-31</td>
</tr>
<tr>
<td>Figure 3-13</td>
<td>Striped Bass Movements during a Change in BAFF Operations (OFF to ON), 2011 Study at Georgiana Slough</td>
<td>3-32</td>
</tr>
<tr>
<td>Figure 3-14</td>
<td>Percentage of Total Occupation Time by Spatial Polygon for Predatory Fish Species Combined under BAFF ON and BAFF OFF Conditions</td>
<td>3-33</td>
</tr>
<tr>
<td>Figure 3-15</td>
<td>Two-Dimensional Near-Surface Particle Pathlines at the Head of Old River, May 2012</td>
<td>3-34</td>
</tr>
<tr>
<td>Figure 3-16</td>
<td>Conceptual Design for Physical Barrier at the Head of Old River</td>
<td>3-35</td>
</tr>
<tr>
<td>Figure 3-17</td>
<td>Percentage of Tag Detections for Five Channel Catfish at Different Near-Surface Velocities at the Head of Old River Study Area</td>
<td>3-36</td>
</tr>
<tr>
<td>Figure 3-18</td>
<td>Percentage of Tag Detections for Seven Largemouth Bass at Different Near-Surface Velocities at the Head of Old River Study Area</td>
<td>3-37</td>
</tr>
<tr>
<td>Figure 3-19</td>
<td>Percentage of Tag Detections for Four Striped Bass at Different Near-Surface Velocities at the Head of Old River Study Area</td>
<td>3-38</td>
</tr>
<tr>
<td>Figure 3-20</td>
<td>Alignments of BAFFs Installed at the Head of Old River in 2009 and 2010, shown with Proposed Alignment for 2011 BAFF</td>
<td>3-39</td>
</tr>
<tr>
<td>Figure 4-1</td>
<td>Alignment of the Proposed BAFF at Georgiana Slough (in black) and Recent Study Alignments (in red)</td>
<td>4-4</td>
</tr>
<tr>
<td>Figure 4-2</td>
<td>Elevation View of the Alignment of the Proposed BAFF at Georgiana Slough</td>
<td>4-5</td>
</tr>
<tr>
<td>Figure 4-3</td>
<td>Plan View of the Proposed FFGS at Georgiana Slough, Showing Angle-to-Flow, Vertex, and Point of Divergence</td>
<td>4-6</td>
</tr>
<tr>
<td>Figure 4-4</td>
<td>Plan View of the Proposed FFGS at Georgiana Slough, Including Alignment and Boat Passage</td>
<td>4-7</td>
</tr>
<tr>
<td>Figure 4-5</td>
<td>Elevation View of the Proposed FFGS at Georgiana Slough, Showing Depth of Barrier and Boat Passage Location</td>
<td>4-8</td>
</tr>
<tr>
<td>Figure 4-6</td>
<td>Detail Drawing of the Proposed FFGS at Georgiana Slough, Showing the 5-foot and 10 foot Panels</td>
<td>4-9</td>
</tr>
<tr>
<td>Figure 4-7</td>
<td>Images Showing Two IFF Units per Pallet (left) and Example IFF Alignment with Floats and Cables (right)</td>
<td>4-10</td>
</tr>
<tr>
<td>Figure 4-8</td>
<td>Plan View of the Proposed IFF at Georgiana Slough Showing Locations of the IFF and the Boat Passage BAFF</td>
<td>4-11</td>
</tr>
<tr>
<td>Figure 4-9</td>
<td>Elevation View of the Proposed 875-foot-long IFF at Georgiana Slough Including the 100-foot BAFF</td>
<td>4-12</td>
</tr>
<tr>
<td>Figure 4-10</td>
<td>Plan View of the Proposed Gates with Boat Lock and Fish Ladder at Georgiana Slough Showing the Gate System Alignment</td>
<td>4-13</td>
</tr>
<tr>
<td>Figure 4-11</td>
<td>Alignment of the Proposed BAFF at Threemile Slough</td>
<td>4-14</td>
</tr>
<tr>
<td>Figure 4-12</td>
<td>Elevation View of the Alignment of the Proposed BAFF at Threemile Slough (Stations 0+00 through 14+00)</td>
<td>4-15</td>
</tr>
<tr>
<td>Figure 4-13</td>
<td>Elevation View of the Alignment of the Proposed BAFF at Threemile Slough (Stations 14+00 through 28+00)</td>
<td>4-16</td>
</tr>
<tr>
<td>Figure 4-14</td>
<td>Plan View of the Proposed FFGS at Threemile Slough</td>
<td>4-17</td>
</tr>
<tr>
<td>Figure 4-15</td>
<td>Elevation View of the Northern Portion of the Proposed FFGS at Threemile Slough</td>
<td>4-18</td>
</tr>
<tr>
<td>Figure 4-16</td>
<td>Elevation View of the Southern Portion of the Proposed FFGS at Threemile Slough</td>
<td>4-19</td>
</tr>
</tbody>
</table>
## TABLE OF CONTENTS

| Figure 4-17 | Detail Drawing of the Proposed FFGS at Threemile Slough, Showing the 5-foot and 10-foot Panels | 4-33 |
| Figure 4-18 | Layout of the Proposed IFF at the Threemile Slough Divergence | 4-35 |
| Figure 4-19 | Elevation View of the Alignment of the Proposed IFF at Threemile Slough (Stations 0+00 through 14+00) | 4-36 |
| Figure 4-20 | Elevation View of the Alignment of the Proposed IFF at Threemile Slough (Stations 14+00 through 28+00) | 4-37 |
| Figure 4-21 | Plan View of the Proposed Gate Structure at Threemile Slough | 4-41 |
| Figure 4-22 | Proposed Boat Lock System for the Threemile Slough Location | 4-42 |
| Figure 4-23 | BAFF at the HOR during the 2009 Test Period | 4-45 |
| Figure 4-24 | Layout of the Proposed BAFF at the Head of Old River | 4-46 |
| Figure 4-25 | Elevation View of the Proposed BAFF at the Head of Old River | 4-47 |
| Figure 4-26 | Layout of the Proposed FFGS at the Head of Old River | 4-50 |
| Figure 4-27 | Elevation View of the Proposed FFGS at the Head of Old River | 4-51 |
| Figure 4-28 | Detailed Drawing of the 2-foot FFGS Panel | 4-52 |
| Figure 4-29 | Typical Obermeyer Gates Installed in the Kinta River, Perak, Malaysia | 4-54 |
| Figure 4-30 | Proposed SDIP Gate Structure at the Head of Old River | 4-55 |
| Figure 4-31 | Proposed Head of Old River gate structure design | 4-59 |
| Figure 4-32 | Delta Cross Channel Radial Arm Gates on the left and Obermeyer Gates Installed in Kinta River, Perak Malaysia on the right | 4-59 |
| Figure 4-33 | Layout of the Proposed BAFFs at Turner Cut | 4-62 |
| Figure 4-34 | Elevation View of the Proposed East Channel BAFF Alignment | 4-63 |
| Figure 4-35 | Elevation View of the Proposed West Channel BAFF Alignment | 4-64 |
| Figure 4-36 | Layout of the Proposed FFGS at Turner Cut | 4-68 |
| Figure 4-37 | Elevation View of the Proposed FFGSs and the Barrier Depth at Turner Cut | 4-68 |
| Figure 4-38 | Plan View of the Proposed FFGS at the West Channel of Turner Cut | 4-69 |
| Figure 4-39 | Detailed Drawing of the 5-foot and 10-foot FFGS Panels | 4-71 |
| Figure 4-40 | Layout of the Proposed IFF at Turner Cut | 4-73 |
| Figure 4-41 | Elevation View of the Proposed East Channel and West Channel IFF Alignment | 4-74 |
| Figure 4-42 | Delta Cross Channel Radial Arm Gates on the left and Obermeyer Gates Installed in Kinta River, Perak, Malaysia on the right | 4-77 |
| Figure 4-43 | Proposed Turner Cut Gate Structure Design | 4-78 |
| Figure 4-44 | BAFF Alignment at Columbia Cut | 4-81 |
| Figure 4-45 | Elevation View of the Proposed BAFF Alignment | 4-83 |
| Figure 4-46 | Plan View of the FFGS at Columbia Cut | 4-86 |
| Figure 4-47 | Elevation View of Both Channels | 4-87 |
| Figure 4-48 | Detailed Drawing of the FFGS showing the 5-foot and 10-foot Panels | 4-89 |
| Figure 4-49 | Plan View of the IFF at the Two-Channel Splt | 4-92 |
| Figure 4-50 | Plan View of the Gates, Vertical Slot Fish Ladder, and Boat Lock | 4-95 |
| Figure 4-51 | Elevation View of the Gate Structure at Columbia Cut | 4-96 |
### TABLE OF CONTENTS

#### Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table ES-1</td>
<td>Final Evaluation Criteria to Evaluate Engineering Options</td>
<td>ES-6</td>
</tr>
<tr>
<td>Table ES-2</td>
<td>WRAM Final Coefficients</td>
<td>ES-8</td>
</tr>
<tr>
<td>Table 2-1</td>
<td>Federally and State-listed Fish, Candidate Fish for Listing, and Fish Species of Concern in the Delta</td>
<td>2-13</td>
</tr>
<tr>
<td>Table 2-2</td>
<td>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</td>
<td>2-15</td>
</tr>
<tr>
<td>Table 2-3</td>
<td>Annual Production Goals and Percent Trucked for Central Valley Hatcheries that Produce Anadromous Salmonids</td>
<td>2-59</td>
</tr>
<tr>
<td>Table 3-1</td>
<td>Key Components of 2009 and 2010 Testing at the Head of Old River Study Area</td>
<td>3-4</td>
</tr>
<tr>
<td>Table 3-2</td>
<td>Summary of Mean Efficiency Values</td>
<td>3-7</td>
</tr>
<tr>
<td>Table 3-3</td>
<td>Summary of Mean Efficiency Values</td>
<td>3-12</td>
</tr>
<tr>
<td>Table 3-4</td>
<td>Key Components of 2014 Testing at the Georgiana Slough Study Area</td>
<td>3-18</td>
</tr>
<tr>
<td>Table 3-5</td>
<td>Reported Swimming Capacity of Juvenile Chinook Salmon in North America</td>
<td>3-25</td>
</tr>
<tr>
<td>Table 3-6</td>
<td>Reported Swimming Capacity of Hatchery-Reared Steelhead in North America</td>
<td>3-26</td>
</tr>
<tr>
<td>Table 3-7</td>
<td>Summary of Current and Recently Completed Related Studies in the Legal Delta</td>
<td>3-52</td>
</tr>
<tr>
<td>Table 3-8</td>
<td>Final Evaluation Criteria to Evaluate Engineering Options</td>
<td>3-61</td>
</tr>
<tr>
<td>Table 5-1</td>
<td>WRAM Relative Importance Coefficients</td>
<td>5-2</td>
</tr>
<tr>
<td>Table 5-2</td>
<td>WRAM Option Choice Coefficients</td>
<td>5-3</td>
</tr>
<tr>
<td>Table 5-3</td>
<td>WRAM Final Coefficients</td>
<td>5-4</td>
</tr>
<tr>
<td>Table 6-1</td>
<td>Effectiveness Monitoring of Engineered Fish Barriers</td>
<td>6-3</td>
</tr>
<tr>
<td>Table 6-2</td>
<td>Key Uncertainties and Potential Research Actions Relevant to Evaluating Engineering Solutions</td>
<td>6-3</td>
</tr>
</tbody>
</table>
ACRONYMS AND OTHER ABBREVIATIONS

°C   degrees Celsius
°F   degrees Fahrenheit
λ    wavelength
2D   two-dimensional
3D   three-dimensional

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”

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
BL/s  body lengths per second
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
CVPIA Central Valley Project Improvement Act
DCC   Delta Cross Channel
D_e   Deterrence efficiency
Delta  Sacramento–San Joaquin River Delta
DFG   California Department of Fish and Game (see CDFW)
DIDSON Dual-Frequency Identification Sonar
DPS   Distinct Population Segment
DSM2 Hydro PTM Delta Simulation Model 2 Hydro Particle Tracking Model
DWR   California Department of Water Resources
EFH   Essential Fish Habitat
ELAM  Eulerian-Lagrangian-Agent Method
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMC</td>
<td>electromagnetic compatibility</td>
</tr>
<tr>
<td>EPRI</td>
<td>Electric Power Research Institute</td>
</tr>
<tr>
<td>ESA</td>
<td>Endangered Species Act</td>
</tr>
<tr>
<td>ESU</td>
<td>Evolutionarily Significant Unit</td>
</tr>
<tr>
<td>FC</td>
<td>final coefficient</td>
</tr>
<tr>
<td>FFAS</td>
<td>Fishing Facility Access Structure</td>
</tr>
<tr>
<td>FFGS</td>
<td>Floating Fish Guidance Structure</td>
</tr>
<tr>
<td>FGS</td>
<td>Fish Guidance Systems, Ltd.</td>
</tr>
<tr>
<td>FL</td>
<td>fork length</td>
</tr>
<tr>
<td>FR</td>
<td>Federal Register</td>
</tr>
<tr>
<td>FTP</td>
<td>Franks Tract Project</td>
</tr>
<tr>
<td>GCID</td>
<td>Glenn Colusa Irrigation District</td>
</tr>
<tr>
<td>GLM</td>
<td>generalized linear model</td>
</tr>
<tr>
<td>GSNPB</td>
<td>Georgiana Slough Non-Physical Barrier</td>
</tr>
<tr>
<td>HIL</td>
<td>High Intensity Light</td>
</tr>
<tr>
<td>HOR</td>
<td>Head of Old River</td>
</tr>
<tr>
<td>HORB</td>
<td>Head of Old River Barrier</td>
</tr>
<tr>
<td>Hz</td>
<td>Hertz</td>
</tr>
<tr>
<td>IFF</td>
<td>Infrasound Fish Fence</td>
</tr>
<tr>
<td>kW</td>
<td>kilowatt</td>
</tr>
<tr>
<td>LED</td>
<td>light-emitting diode</td>
</tr>
<tr>
<td>LSZ</td>
<td>low-salinity zone</td>
</tr>
<tr>
<td>m</td>
<td>meter</td>
</tr>
<tr>
<td>M</td>
<td>million</td>
</tr>
<tr>
<td>MID</td>
<td>Merced Irrigation District</td>
</tr>
<tr>
<td>mm</td>
<td>millimeters</td>
</tr>
<tr>
<td>m/s</td>
<td>meters per second</td>
</tr>
<tr>
<td>N</td>
<td>sample size</td>
</tr>
<tr>
<td>NAVD88</td>
<td>North American Vertical Datum of 1988</td>
</tr>
<tr>
<td>nm</td>
<td>nanometer</td>
</tr>
<tr>
<td>NMFS</td>
<td>National Marine Fisheries Service</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
</tr>
<tr>
<td>NPB</td>
<td>non-physical barrier</td>
</tr>
<tr>
<td>OCC</td>
<td>option choice coefficient</td>
</tr>
<tr>
<td>O_e</td>
<td>overall efficiency</td>
</tr>
<tr>
<td>OMR</td>
<td>Old and Middle River</td>
</tr>
</tbody>
</table>
# ACRONYMS AND OTHER ABBREVIATIONS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCR</td>
<td>Polymerase Chain Reaction</td>
</tr>
<tr>
<td>P_E</td>
<td>Protection efficiency</td>
</tr>
<tr>
<td>Phase I Report</td>
<td>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</td>
</tr>
<tr>
<td>Phase II Report</td>
<td>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]</td>
</tr>
<tr>
<td>ppt</td>
<td>parts per thousand</td>
</tr>
<tr>
<td>RBDD</td>
<td>Red Bluff Diversion Dam</td>
</tr>
<tr>
<td>Reclamation</td>
<td>U.S. Department of the Interior, Bureau of Reclamation</td>
</tr>
<tr>
<td>RIC</td>
<td>relative importance coefficient</td>
</tr>
<tr>
<td>RM</td>
<td>river mile</td>
</tr>
<tr>
<td>RPA</td>
<td>Reasonable and Prudent Alternative</td>
</tr>
<tr>
<td>SDIP</td>
<td>South Delta Improvement Program</td>
</tr>
<tr>
<td>SFPF</td>
<td>Skinner Fish Protection Facility</td>
</tr>
<tr>
<td>Study</td>
<td>Phases I, II, and III of the Action (see Action)</td>
</tr>
<tr>
<td>SWP</td>
<td>State Water Project</td>
</tr>
<tr>
<td>T_4</td>
<td>throxine</td>
</tr>
<tr>
<td>TFCF</td>
<td>Tracy Fish Collection Facility</td>
</tr>
<tr>
<td>TL</td>
<td>total body length</td>
</tr>
<tr>
<td>TWG</td>
<td>Technical Working Group</td>
</tr>
<tr>
<td>UCD</td>
<td>University of California, Davis</td>
</tr>
<tr>
<td>U-crit</td>
<td>critical swimming speed</td>
</tr>
<tr>
<td>UCSC</td>
<td>University of California, Santa Cruz</td>
</tr>
<tr>
<td>USACE</td>
<td>U.S. Army Corps of Engineers</td>
</tr>
<tr>
<td>USBR</td>
<td>U.S. Department of the Interior, Bureau of Reclamation (see Reclamation)</td>
</tr>
<tr>
<td>USFWS</td>
<td>U.S. Fish and Wildlife Service</td>
</tr>
<tr>
<td>USGS</td>
<td>U.S. Geological Survey</td>
</tr>
<tr>
<td>UV</td>
<td>ultraviolet</td>
</tr>
<tr>
<td>VAMP</td>
<td>Vernalis Adaptive Management Plan</td>
</tr>
<tr>
<td>WES</td>
<td>Waterways Experiment Station</td>
</tr>
<tr>
<td>WRAM</td>
<td>Water Resource Assessment Methodology</td>
</tr>
</tbody>
</table>
EXECUTIVE SUMMARY

ES.1 INTRODUCTION


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: 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.
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. 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 in 2011 (DWR 2012) and 2012 at Georgiana Slough (DWR 2014a in prep.). U.S. Geological Survey (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.

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 the 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.

<table>
<thead>
<tr>
<th>Cost Comparison - Site Specific Engineering Options</th>
<th>Initial Construction</th>
<th>Annual O&amp;M</th>
<th>Present Worth</th>
</tr>
</thead>
<tbody>
<tr>
<td>GS</td>
<td>BAFF</td>
<td>$12,800,000</td>
<td>$510,000</td>
</tr>
<tr>
<td></td>
<td>FFGS</td>
<td>$6,300,000</td>
<td>$340,000</td>
</tr>
<tr>
<td></td>
<td>IFF</td>
<td>$7,600,000</td>
<td>$390,000</td>
</tr>
<tr>
<td></td>
<td>Gate</td>
<td>$47,100,000</td>
<td>$200,000</td>
</tr>
<tr>
<td>TMS</td>
<td>BAFF</td>
<td>$35,400,000</td>
<td>$880,000</td>
</tr>
<tr>
<td></td>
<td>FFGS</td>
<td>$12,800,000</td>
<td>$710,000</td>
</tr>
<tr>
<td></td>
<td>IFF</td>
<td>$17,400,000</td>
<td>$790,000</td>
</tr>
<tr>
<td></td>
<td>FTP</td>
<td>$148,400,000</td>
<td>$210,000</td>
</tr>
<tr>
<td>HOR</td>
<td>BAFF</td>
<td>$6,800,000</td>
<td>$440,000</td>
</tr>
<tr>
<td></td>
<td>FFGS</td>
<td>$800,000</td>
<td>$130,000</td>
</tr>
<tr>
<td></td>
<td>SDIP</td>
<td>$41,200,000</td>
<td>$200,000</td>
</tr>
<tr>
<td></td>
<td>Gate</td>
<td>$43,200,000</td>
<td>$200,000</td>
</tr>
<tr>
<td>TC</td>
<td>BAFF</td>
<td>$18,500,000</td>
<td>$860,000</td>
</tr>
<tr>
<td></td>
<td>FFGS</td>
<td>$7,200,000</td>
<td>$390,000</td>
</tr>
<tr>
<td></td>
<td>IFF</td>
<td>$6,500,000</td>
<td>$390,000</td>
</tr>
<tr>
<td></td>
<td>Gate</td>
<td>$70,000,000</td>
<td>$200,000</td>
</tr>
<tr>
<td>CC</td>
<td>BAFF</td>
<td>$16,600,000</td>
<td>$840,000</td>
</tr>
<tr>
<td></td>
<td>FFGS</td>
<td>$7,600,000</td>
<td>$450,000</td>
</tr>
<tr>
<td></td>
<td>IFF</td>
<td>$8,400,000</td>
<td>$440,000</td>
</tr>
<tr>
<td></td>
<td>Gate</td>
<td>$82,100,000</td>
<td>$270,000</td>
</tr>
</tbody>
</table>

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 potential preferred option at each of the five sites were:

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

The final coefficients for each of the study sites are shown in Table ES-2.

<table>
<thead>
<tr>
<th>Table ES-2. WRAM Final Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Site</strong></td>
</tr>
<tr>
<td>Georgiana Slough</td>
</tr>
<tr>
<td>Threemile Slough</td>
</tr>
<tr>
<td>Head of Old River</td>
</tr>
<tr>
<td>Turner Cut</td>
</tr>
<tr>
<td>Columbia Cut</td>
</tr>
</tbody>
</table>

Notes: Data submitted from NMFS, CDFW, and DWR compiled by DWR in 2014.

ES.6 RECOMMENDATIONS

During the past five years, a large effort was invested into researching and field testing technologies identified in the Phase I Report. There are still unknowns that exist to fully understand how effective each of the technologies would perform over the full range of flows if constructed. Untested engineering technologies, better understanding of hydrodynamic interactions with engineering technologies, specific gate operations, and predation interactions with the engineering technologies could be better understood.
In moving forward to implement options in Phase III at each of the junctions addressed in this report, additional research and monitoring should be considered. Unfortunately, unlimited resources and time are not available to eliminate all of the uncertainties.

A few items to consider are:

► Review of current studies related to the Action when they are completed.
► Additional field study of an FFGS pending results from the 2014 study.
► Field testing of an IFF to determine deterrence ability.
► Modeling of specific gate operations for the gate options.
► Additional hydrodynamic modeling coinciding with field study to observe engineering technology performance.
► Implement 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.

The engineering options that are eventually implemented at one or more of the five sites reviewed in this report will be subject to an adaptive management and monitoring program designed to use new information and insight gained during the course of a specific engineering treatment to 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. Effectiveness monitoring will consist of assessing the effectiveness of each barrier. Results of effectiveness monitoring to determine whether operations of barriers result 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.
This page intentionally left blank.
1 INTRODUCTION

1.1 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 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 Option (to be determined).

This Phase II Report is the culmination of Phase II and presents potential engineering solutions for five key Delta locations. These potential solutions are based on consideration of aspects of engineering, biological, and social importance including: 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
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 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 (sites);

► 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 Technical Working Group (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 Central Valley steelhead (*O. mykiss*);
- Threatened Southern DPS of 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 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 CDFG, 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 what 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 potential 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 2010 (BAFF), 2011 (BAFF), and 2014 (FFGS) at Georgiana Slough, preparing conceptual 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 38.23947°, Longitude -121.51726°). 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 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 monthly flow ranges between 2,200 to 6,200 cubic feet per second (cfs). Georgiana Slough is approximately 200 feet wide and 20 to 30 feet deep at its divergence from the Sacramento River during average 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 38.1067°, Longitude -121.7023°). 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 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 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. Monthly flows average 2,000 cfs, depending on the river flows and the tidal cycle. 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 37.8076°, Longitude -121.3277°) (Figure 2-3). Adjacent land use is 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**
Figure 2-3. Head of Old River
This study site area is a migratory corridor for 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 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 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 due to pumping for water export. 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 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 non-anadromous delta smelt, Sacramento pikeminnow, Sacramento splittail, and various catfish species. Columbia Cut provides similar recreational opportunities as the other sites.
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. 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, Central Valley (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

<table>
<thead>
<tr>
<th>Species</th>
<th>Listing Status</th>
<th>Designated Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Federal①</td>
<td>State②</td>
</tr>
<tr>
<td>Sacramento River winter-run Chinook salmon ESU (<em>Oncorhynchus tshawytscha</em>)</td>
<td>FE</td>
<td>SE</td>
</tr>
<tr>
<td>Central Valley spring-run Chinook salmon ESU (<em>O. tshawytscha</em>)</td>
<td>FT</td>
<td>ST</td>
</tr>
<tr>
<td>Central Valley fall-run Chinook salmon ESU (<em>O. tshawytscha</em>)</td>
<td>FC</td>
<td>SSC</td>
</tr>
<tr>
<td>Central Valley late fall-run Chinook salmon ESU (<em>O. tshawytscha</em>)</td>
<td>FC</td>
<td>SSC</td>
</tr>
<tr>
<td>Central Valley steelhead DPS (<em>O. mykiss</em>)</td>
<td>FT</td>
<td>--</td>
</tr>
<tr>
<td>Delta smelt (<em>Hypomesus transpacificus</em>)</td>
<td>FT</td>
<td>ST</td>
</tr>
<tr>
<td>Southern DPS green sturgeon (<em>Acipenser medirostris</em>)</td>
<td>FT</td>
<td>SSC</td>
</tr>
<tr>
<td>Longfin smelt (<em>Spirinchus thaleichthys</em>)</td>
<td>FC</td>
<td>ST</td>
</tr>
<tr>
<td>River lamprey (<em>Lampetra ayresii</em>)</td>
<td>--</td>
<td>SSC</td>
</tr>
<tr>
<td>Hardhead (<em>Mylopharodon conocephalus</em>)</td>
<td>--</td>
<td>SSC</td>
</tr>
<tr>
<td>Sacramento perch (<em>Archoplites interruptus</em>)</td>
<td>--</td>
<td>SSC</td>
</tr>
<tr>
<td>Tidewater goby (<em>Eucyclogobius newberryi</em>)</td>
<td>FE</td>
<td>SSC</td>
</tr>
<tr>
<td>Rough sculpin (<em>Cottus asperrimus</em>)</td>
<td>--</td>
<td>ST; FP</td>
</tr>
</tbody>
</table>

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
- 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. Months present by life stage of Chinook salmon include:

- Infant: February to May
- Juvenile: February to May
- Spawning: Late February to May
salmon runs and steelhead in the Sacramento and San Joaquin rivers is shown 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). Furthermore, fork length ranges of juvenile Chinook salmon have been historically and are currently used to differentiate winter-run and spring-run within the four runs. However, recent analysis showed that 49% of fork length for genetically identified juveniles occurred outside the expected length-at-date ranges for their respective races, and had a high degree of overlap in fork length ranges among the four races (Harvey et al. 2014).

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 rearig 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. Juveniles may rear in freshwater for a year or more before emigrating to the ocean; 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 is present in Central Valley rivers and streams (McEwan and Jackson 1996), although indications show that summer-run steelhead historically was present in the Sacramento River system (Moyle 2002). Although adult Central Valley steelhead exhibit very plastic life history strategies, 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 Central Valley 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).
### 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

<table>
<thead>
<tr>
<th>Life Stage</th>
<th>Species</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Adult Migration</strong></td>
<td>Winter-Run</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spring-Run</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fall-Run SR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fall-Run SJR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Late Fall-Run</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Steelhead SR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Steelhead SJR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Spawning</strong></td>
<td>Winter-Run</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spring-Run</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fall-Run SR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fall-Run SJR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Late Fall-Run</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Steelhead SR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Steelhead SJR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Egg Incubation and</strong></td>
<td>Winter-Run</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Emergence</strong></td>
<td>Spring-Run</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fall-Run SR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fall-Run SJR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Late Fall-Run</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Steelhead SR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Steelhead SJR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Juvenile Rearing</strong></td>
<td>Winter-Run</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spring-Run</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fall-Run SR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fall-Run SJR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Late Fall-Run</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Steelhead SR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Steelhead SJR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Smolt Emigration</strong></td>
<td>Winter-Run</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spring-Run</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fall-Run SR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fall-Run SJR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Late Fall-Run</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Steelhead SR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Steelhead SJR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: 
= Delta Migration

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 confined Sacramento River winter-run Chinook salmon to the mainstem Sacramento River and Battle Creek, where they are highly dependent on cool water releases from Shasta Dam for 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 has declined dramatically 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 (°F) to 56°F (Bell 1991), but water temperatures up to 67°F 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, dam operations, and water year type.

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 55°F and 56°F are ideal for gamete development and egg viability. Suitability for holding adults begins to decline when water temperatures rise above 59°F to 60°F (DWR 1988; NMFS 1997). Water temperatures above 69.8°F 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 below 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 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 a physiological change known as 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 Central Valley Chinook salmon, remain localized, primarily in California coastal waters.

Central Valley Spring-Run Chinook Salmon ESU

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).
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 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 and construction of water diversions 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 hatchery origin (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.

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 populations 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 fall-run Chinook salmon show little dependence on estuaries after smoltification begins and may benefit from expedited ocean entry. MacFarlane and Norton (2002) found that juvenile fall-run Chinook salmon spent about 40 days rearing in the estuary and demonstrated little or no real estuarine dependence on growth and 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, remains localized primarily in California coastal waters.

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 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 Thomas 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 mainstream 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). Only winter-run steelhead is present in Central Valley streams (McEwan and Jackson 1996), although there are indications that summer-run steelhead was historically present in the Sacramento and San Joaquin river systems. Summer-run steelhead is 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 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 fry Chinook salmon 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, fry Chinook salmon 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 Estuary and grow little in length or weight until they reached the Gulf of the Farallons (MacFarlane and Norton 2002). 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

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, green sturgeon is listed by CDFW as a State 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 is 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 during some time period. 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). The abundance of adult green sturgeon in the Sacramento River system is not known, but all indications are that numbers are low. 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 above Red Bluff Diversion Dam (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 is slow growing and well-adapted for benthic feeding. In the Delta, juvenile fish 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 cobbles 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). 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). 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).

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 reach 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). 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 on the Sacramento River and Mossdale 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.

Adult delta smelt migrate upstream into channels and sloughs of the Delta 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 submersgent 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 14 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). Newly hatched delta smelt have a large oil globule that makes them semi-buoyant, allowing them to maintain position just off the bottom where they feed on rotifers and other microscopic prey. Larvae become more buoyant as the swim bladder develops and rise up higher into the water column. At this stage and 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 into the mixing zone or the area immediately upstream (Moyle 2002). This area has the highest 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). Larva 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.

### 2.2.3 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.

### 2.2.4 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.

#### 2.2.4.1 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.

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

Figure 2-12. Typical Radial Arm Gate
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 OCAP 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).
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.

![Aerial View of the Head of Old River Rock Barrier](image)

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 straightforward 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).

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.

![Three Sections of a Floating Fish Guidance Structure](source: Worthington Waterway Barriers 2013)
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.
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.

### 2.2.4.2 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 South Hampton, 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 2012 a, 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 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 nm 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 convergences. 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.

![Two-Dimensional Trace of a Tagged Juvenile Chinook at the Head of Old River in 2009](image-url)

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.
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 (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 spacing in 2D.

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.
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:

\[ D = \frac{E}{E+U} \]

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:

\[ P = \frac{S}{S+O} \]

where:

- \( P \) = Protection Efficiency,
- \( S \) = the number of fish passing down into the San Joaquin River, and
- \( O \) = the number of fish 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, 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 (5 to 600 Hz). 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:

\[ D = \frac{B}{B+C} \]

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:

\[ P = \frac{F}{F+G} \]

where:

- \( P \) = Protection Efficiency,
- \( F \) = the number of fish passing down into the Sacramento River, and
- \( G \) = the number of fish 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, or through the bubble curtain. A fish passage structure is not necessary to accommodate fish movements.
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 overcome the flow. This may render the BAFF less effective because fish may have a behavioral response, but physically would not be able to avoid entrainment. This would be accentuated 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.
Figure 2-24. Installation of an Electrical Fish Guidance System

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 infrasonic 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.
The Otolith Organ

- Part of the inner ear (accelerometer)
- Grows throughout the fish’s life
- Predator – Prey interaction
- Directional sensitivity

Source: DWR 2014

**Figure 2-26. Schematic of an Otolith Organ**

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: 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).
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.

2.2.4.3 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 predetermined 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>
<thead>
<tr>
<th>Hatchery</th>
<th>Run Produced</th>
<th>Operator/Owner</th>
<th>Annual Production Target</th>
<th>Percent Trucked</th>
<th>Release Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coleman</td>
<td>Fall, Late-fall, Winter</td>
<td>USFWS/Reclamation</td>
<td>F = 12 million, LF = 1 million, Steelhead = 600,000</td>
<td>F = 10%, LF = 0%</td>
<td>0%</td>
</tr>
<tr>
<td>Livingston Stone</td>
<td>Winter</td>
<td>USFWS/Reclamation</td>
<td>250,000</td>
<td>NA</td>
<td>0%</td>
</tr>
<tr>
<td>Feather River</td>
<td>Fall, Spring</td>
<td>CDFW/DWR</td>
<td>F = 8 million, S = 5 million, Steelhead = 450,000</td>
<td>F = 100%, S = 25%, 0%</td>
<td>0%</td>
</tr>
<tr>
<td>Nimbus</td>
<td>Fall</td>
<td>CDFW/Reclamation</td>
<td>4 million</td>
<td>Steelhead = 400,000</td>
<td>40%</td>
</tr>
<tr>
<td>Mokelumne River</td>
<td>Fall</td>
<td>CDFW/EBMUD</td>
<td>5 million</td>
<td>Steelhead = 250,000</td>
<td>100%</td>
</tr>
<tr>
<td>Merced River</td>
<td>Fall</td>
<td>CDFW/MID</td>
<td>1 million</td>
<td>NA</td>
<td>0%</td>
</tr>
</tbody>
</table>

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

Table 2.3. Annual Production Goals and Percent Trucked for Central Valley Hatcheries that Produce Anadromous Salmonids

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 barge 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.
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 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 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. 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) 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 as 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.
Figure 3-1. Overview of the 2009 and 2010 Head of Old River Non-Physical Barrier Study Area
# Key Components of 2009 and 2010 Testing at the Head of Old River Study Area

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dates of Fish Releases</td>
<td>April 22, 2009– May 13, 2009</td>
<td>April 27, 2010– May 19, 2010</td>
</tr>
<tr>
<td>Number of Study Fish</td>
<td>933</td>
<td>504</td>
</tr>
<tr>
<td>Source of Fish</td>
<td>Fall-Spring hybrid run Chinook Salmon from Feather River Fish Hatchery</td>
<td>Fall-run Chinook Salmon from Merced River Hatchery</td>
</tr>
<tr>
<td>Release Location</td>
<td>Durham Ferry, San Joaquin River</td>
<td>Durham Ferry, San Joaquin River</td>
</tr>
<tr>
<td>Release Details</td>
<td>Seven releases of about 135 juveniles per release, two releases per day (17:00=daylight release, 21:00 nighttime release)</td>
<td>Seven releases of about 74 juveniles per release, four releases per day. Releases occurred approximately at 1400, 2000, 0200, and 0800 (SJRGA 2011: Table 5-1)</td>
</tr>
<tr>
<td>Array Details</td>
<td>Four hydrophones installed around the BAFF (2D array) and one fixed station in the Old River downstream</td>
<td>Eight hydrophones installed around the BAFF, four upstream and four downstream</td>
</tr>
<tr>
<td>Barrier Length and Configuration</td>
<td>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.</td>
<td>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.</td>
</tr>
</tbody>
</table>

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.

---

**Figure 3-2.** Head of Old River Study Area – 2009 Hydrophone Array and BAFF in Place (red line).
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 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), reflecting 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 to account for potential differences in 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.
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

At 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. This metric 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

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 was less appropriate than analyzing using BAFF state, light, and velocity. So, they placed the tags into samples based on BAFF, light, and velocity and reanalyzed and the analysis made more sense, produced more samples, and was more robust. Therefore, the results from DWR 2014b are reported herein.
Table 3.2. Summary of Mean Efficiency Values

<table>
<thead>
<tr>
<th>Year</th>
<th>Overall Efficiency ($O_E$)</th>
<th>Protection Efficiency ($P_E$)</th>
<th>Deterrence Efficiency ($D_E$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>On</td>
<td>Off</td>
<td>% Change</td>
</tr>
<tr>
<td>2009</td>
<td>20.9%</td>
<td>18.4%</td>
<td>2.5%</td>
</tr>
<tr>
<td>2010</td>
<td>35.5%</td>
<td>24.5%</td>
<td>11.0%</td>
</tr>
</tbody>
</table>

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 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 in 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 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.

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 associate 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 study.

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

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

• 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 barrier and were deterred from entering Georgiana Slough and instead remained in the Sacramento River;

    • $P_E$: 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 between the 2 years (Table 3-3). 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>
<thead>
<tr>
<th>Year</th>
<th>Overall Efficiency (( O_E ))</th>
<th>Protection Efficiency (( P_E ))</th>
<th>Deterrence Efficiency (( D_E ))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>On %</td>
<td>Off %</td>
<td>Change</td>
</tr>
<tr>
<td>2011</td>
<td>89.1%</td>
<td>73.4%</td>
<td>15.7%</td>
</tr>
<tr>
<td>2012</td>
<td>89.7%</td>
<td>75.2%</td>
<td>14.5%</td>
</tr>
</tbody>
</table>

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 between the two years. The deterrence efficiency when the BAFF was on was 56.1 percent in 2012 and 50.4 percent in 2011. Protection efficiency when the BAFF was on was 89.0 percent in 2012 and 90.5 percent in 2011. Overall efficiency when the BAFF was on was 89.7 percent in 2012 and 90.8 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 between 2011 and 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
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 among 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 $D_r$, $P_e$, 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, an approximately 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 55 percent) observed for steelhead when the BAFF was ON (10.5 percent) and when it was OFF (23.4 percent). The reduction in the probability that juvenile salmonids would migrate into Georgiana Slough was similar: 22.1 percent with the BAFF OFF to 7.4 percent with the BAFF ON in 2011. 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 or steelhead 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 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
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 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 contribution 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.
Figure 3-5. Study Area Location
Figure 3-6. FFGS Location
Table 3-4.  Key Components of 2014 Testing at the Georgiana Slough Study Area

<table>
<thead>
<tr>
<th>Dates of Fish Releases</th>
<th>February 28, 2014 – April 18, 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Study Fish</td>
<td>5,500 juvenile Chinook salmon and 195 predatory fish</td>
</tr>
<tr>
<td>Study Fish Species</td>
<td>Late fall-run Chinook salmon from Coleman Fish Hatchery</td>
</tr>
<tr>
<td>Release Locations</td>
<td></td>
</tr>
<tr>
<td>Juvenile Chinook salmon released from Sacramento River at the City of Sacramento located approximately 35 river miles upstream of Georgiana Slough</td>
<td></td>
</tr>
<tr>
<td>Juvenile Chinook salmon released into Georgiana Slough approximately 3 miles downstream from the divergence with the Sacramento River</td>
<td></td>
</tr>
<tr>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>Juvenile Chinook Release Details</td>
<td>Sacramento River releases were conducted 8 times per day (0000, 0300, 0900, 1200, 1500, 1800, 2100)</td>
</tr>
<tr>
<td></td>
<td>Georgiana Slough releases were conducted 4 times per day (0300, 0900, 1500, 2100)</td>
</tr>
<tr>
<td>Array Details</td>
<td>About 50 hydrophones were installed around the FFGS (2D array)</td>
</tr>
<tr>
<td>Barrier Length and Configuration</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Straight layout.</td>
</tr>
</tbody>
</table>

Source: Data provided by DWR compiled by AECOM 2014
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 was 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.

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 tagged juveniles exiting downstream from the study area via the Sacramento River, divided by the number of tagged juveniles entering the study area. 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 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 provided 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

Light has the physical attributions of color (wavelength), intensity (irradiance), and polarization. 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, called the retina. The retina 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) ($\lambda_{\text{max}}$: 357–382 nanometers [nm]), blue ($\lambda_{\text{max}}$: 431–446 nm), green ($\lambda_{\text{max}}$: 490–553 nm), and red ($\lambda_{\text{max}}$: 548–607 nm) parts of the spectrum. They also possess a rod visual pigment with peak absorbance ($\lambda_{\text{max}}$) 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, although at night the ambient light is reduced and strobe lights have greater 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). Similarly, 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; Zajac 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 behaviours 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 among other factors. 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 light operation. 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 changed 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 $\lambda_{max}$ of the $\alpha$-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-smolts 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 bifurcation between 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 to the latter. This behaviour seems to be especially present in younger juveniles as 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 were actively swimming away from the lights at night, and showed no preferred swimming direction when the lights were off at night (Johnston et al. 2004). The same response to 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 (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 characteristics of 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 this experiment) 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 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 this 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 that 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. Steelhead screen efficiency may be at acceptable levels. 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. 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 12°C (53.6°F). 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 12°C and 4.91 BL/s at 19°C (66.2°F). 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>
<thead>
<tr>
<th>Fish Length (mm)</th>
<th>Water Temperature (°C)</th>
<th>Source</th>
<th>Swimming Metric</th>
<th>Swimming Speed (body lengths per second)</th>
<th>Swimming Speed Time Interval (minutes)</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>87–96 (SL)¹</td>
<td>17</td>
<td>Wild</td>
<td>U-crit</td>
<td>5.91–6.26</td>
<td>20</td>
<td>Central Valley, CA</td>
</tr>
<tr>
<td>62–79 (SL)²</td>
<td>12</td>
<td>Hatchery</td>
<td>Sustained</td>
<td>4.37–5.56</td>
<td>120</td>
<td>Central Valley, CA</td>
</tr>
<tr>
<td>56–77 (SL)²</td>
<td>19</td>
<td>Hatchery</td>
<td>Sustained</td>
<td>4.91–6.75</td>
<td>120</td>
<td>Central Valley, CA</td>
</tr>
<tr>
<td>91–125 (FL)³</td>
<td>13–16</td>
<td>Wild</td>
<td>U-crit</td>
<td>4.34 ± 1.30 (SD)</td>
<td>30</td>
<td>Columbia River, WA</td>
</tr>
<tr>
<td>122–198 (FL)⁴</td>
<td>16.8–17</td>
<td>Hatchery</td>
<td>U-crit</td>
<td>4.22–4.92</td>
<td>15</td>
<td>Priest Rapids Hatchery, WA</td>
</tr>
</tbody>
</table>

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 ± s.d., in body lengths per second, for the reported size range.
⁴ For Anglea et al. (2004), the swimming speed reported is the range.

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 11°C (51.8°F) and 4.72 BL/s and 19°C.
Table 3-6. Reported Swimming Capacity of Hatchery-Reared Steelhead in North America

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

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 12°C and 4.91 BL/s at 19°C 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 11°C and 4.72 BL/s at 19°C may be used by bioengineers in the design of fish guidance features for juvenile steelhead in the Delta. It is plausible that these values could be applied to Central Valley steelhead. However, steelhead are thought of as better swimmers is twofold: 1) steelhead smolts are often larger than Chinook salmon when outmigrating because they remain in-river longer before departure; and 2) as adults, steelhead are better swimmers and jumpers.

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.

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 near Georgiana Slough

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.
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

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 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).

![Graph showing mean expanded salvage over time of day](image)

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 salmonid 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 (T₄) in juvenile Chinook salmon via radio-immunoassay. Plasma T₄ levels exhibited a cyclic form, with maximum concentrations occurring near each new moon. Because an elevation in T₄ is linked to the onset of smoltification in juvenile Chinook salmon and steelhead (Björnsson et al. 2011; Barron 1986; Dickhoff et al. 1982), and T₄ 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 (fork length [FL] 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 exhibited aggressive and territorial behavior.
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 source population. 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 every condition set, 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, 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 and 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.

### 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.

Whether such simplicity in mechanical types is justified in predictive models is central to the advance of the field of cognitive ecology of fish. In fact, fish are capable of a remarkable array of cognitive powers and have some elaborate sensory physiology that is beyond current understanding (e.g., Willis et al. 2009). For instance, fish develop long-term memories from imprinting at an early life stage. In Atlantic salmon, the location of a natal river has been well established to be imprinted early in life (Keiffer and Colgan 1992). 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, and the barrier’s 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, 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. A 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 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 a river junction, 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). Flow 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 20110 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 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 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 (flow, 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, 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.

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, and are 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”). Marquette and Long (1971) showed that physical screens were successful in deflecting juvenile Chinook salmon and steelhead at velocities of 6 feet per second within turbine intakes; however, such high velocities are not present at the proposed barrier locations in the Central Valley.

If physical barriers are to be used, their design must provide sufficient sweeping velocities along the face of the structure so that stimuli exist to encourage fish to swim into a river or bypass instead of loitering in front of the screens.

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 avoidance will diminish as swimming performance falls off.

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; fish will not 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 their 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 survival, 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. 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.
Delta smelt were deterred by the multiple-stimulus (light/sound/bubble) BAFF (Bowen et al. 2009b) 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. 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 Bridges 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).

![Diagram of components of the predation process](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
weaken 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). High levels of juvenile Chinook salmon predation in the HOR study area were observed with the BAFF ON in 2009–2010 (just over 30 percent mortality) and with the rock barrier in 2012 (just under 40 percent mortality) (DWR 2014b). In contrast, predation was considerably less with the BAFF OFF (16 to 20 percent mortality). Of the 4 years studied, predation was lowest when no barrier was installed in 2011 (10 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 dark conditions compared to light 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 (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.
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

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 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. 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.

![Diagram showing percentage of total occupation time by spatial polygon for predatory fish species combined under BAFF ON and BAFF OFF conditions.](image)

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 IFF, although these remain to be
studied in the Delta. Predatory fish association with the FFGS is still to be tested 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 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 2014c in prep.) 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
Figure 3-16. Conceptual Design for Physical Barrier at the Head of Old River

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 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.
Largemouth Bass (n = 7)

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 at the Head of Old River 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).
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), particularly with respect to the 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 from 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

<table>
<thead>
<tr>
<th>Study Title</th>
<th>Diet Analysis</th>
<th>Piscivorous Predator Behavior</th>
<th>Salmonid Route Selection</th>
<th>Salmonid Survival</th>
<th>Completion Date</th>
<th>Study Location</th>
<th>Lead Agency</th>
<th>Principal Investigator</th>
<th>Funding Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current Studies</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clifton Court Forebay Predation Full-Scale Studies</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>2017</td>
<td>South Delta</td>
<td>DWR</td>
<td>Wunderlich</td>
<td>DWR</td>
</tr>
<tr>
<td>Survival and Migratory Patterns of Juvenile Spring and Full Run Chinook</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2016</td>
<td>Delta</td>
<td>UCD</td>
<td>Klimley</td>
<td></td>
</tr>
<tr>
<td>Central Valley Project Improvement</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>2016</td>
<td>Delta</td>
<td>USFWS</td>
<td>Brandes</td>
<td>TBD</td>
</tr>
<tr>
<td>Six-Year Steelhead Study</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>2016</td>
<td>Delta</td>
<td>USBR</td>
<td>Israel</td>
<td></td>
</tr>
<tr>
<td>San Joaquin River Predator Project</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2015</td>
<td>San Joaquin River</td>
<td>NOAA</td>
<td>Hayes</td>
<td></td>
</tr>
<tr>
<td>North Delta Predation Study</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>2014</td>
<td>North Delta</td>
<td>UCD DWR</td>
<td>Baerwald</td>
<td></td>
</tr>
<tr>
<td>Sacramento River Diversion Predator Project</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>2014</td>
<td>Sacramento River</td>
<td>NOAA</td>
<td>Michel</td>
<td>ERP</td>
</tr>
<tr>
<td><strong>Recently Completed</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clifton Court Forebay Predation Pilot Studies</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>2013/14</td>
<td>South Delta</td>
<td>DWR</td>
<td>Wunderlich</td>
<td>DWR</td>
</tr>
<tr>
<td>Head of Old River Predator Study</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2014</td>
<td>Head of Old River</td>
<td>FF</td>
<td>Kennedy</td>
<td></td>
</tr>
<tr>
<td>Habitat Alteration and Predator Study</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>2014</td>
<td>Mokelumne River</td>
<td>UCSC NOAA</td>
<td>Sabal</td>
<td></td>
</tr>
<tr>
<td>Effects of Predator and Flow Manipulation on Juvenile Chinook Salmon Survival</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2014</td>
<td>Delta</td>
<td>CFS</td>
<td>Cavallo</td>
<td></td>
</tr>
<tr>
<td>Georgiana Slough Non-Physical Barrier Study 2012</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>2014</td>
<td>Georgiana Slough</td>
<td>DWR</td>
<td>McQuirk</td>
<td>DWR</td>
</tr>
<tr>
<td>Central Valley Project Improvement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2014</td>
<td>Delta</td>
<td>USFWS</td>
<td>Brandes</td>
<td></td>
</tr>
<tr>
<td>Distribution, Habitat Use, and Movement Patterns of Sub-adult Striped Bass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2012</td>
<td>Bay-Delta</td>
<td>UCD DWR</td>
<td>LeDoux-Bloom</td>
<td></td>
</tr>
</tbody>
</table>
Table 3-7. Summary of Current and Recently Completed Related Studies in the Legal Delta

<table>
<thead>
<tr>
<th>Study Title</th>
<th>Diet Analysis</th>
<th>Piscivorous Predator Behavior</th>
<th>Salmonid Route Selection</th>
<th>Salmonid Survival</th>
<th>Completion Date</th>
<th>Study Location</th>
<th>Lead Agency</th>
<th>Principal Investigator</th>
<th>Funding Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juvenile Salmonid Routing and Barrier Effectiveness, Predation, and Predatory Fishes at the Head of Old River, 2009-2012</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>2012</td>
<td>Head of Old River</td>
<td>DWR</td>
<td>McQuirk</td>
<td>DWR</td>
<td></td>
</tr>
<tr>
<td>Stipulation Study</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>2012</td>
<td>Old Middle River</td>
<td>DWR</td>
<td>Clark</td>
<td>DWR</td>
<td></td>
</tr>
<tr>
<td>Georgiana Slough Non-Physical Barrier Study 2011</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>2011</td>
<td>Georgiana Slough</td>
<td>DWR</td>
<td>McQuirk</td>
<td>DWR</td>
<td></td>
</tr>
</tbody>
</table>

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 = 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 is 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 a 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 late 2014. See DWR (2014) 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 (39.3 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 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 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 rock barrier in the dark. The proportion of juvenile Chinook salmon entering Old River ranged from 0 percent 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 was 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>
<thead>
<tr>
<th>Table 3-8.</th>
<th>Final Evaluation Criteria to Evaluate Engineering Options</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Criterion</strong></td>
<td><strong>Description</strong></td>
</tr>
<tr>
<td>Boat Passage</td>
<td>The ability of an option to allow for the passage of boat traffic.</td>
</tr>
<tr>
<td>Cost</td>
<td>The cost of initial, annual, and long-term implementation of an option.</td>
</tr>
<tr>
<td>Deterrence Ability</td>
<td>The ability of an option to deter emigrating salmonids from entering a non-preferred migration route.</td>
</tr>
<tr>
<td>Environmental Impacts</td>
<td>Potential impacts of an option on the environment, including aquatic, terrestrial, and air quality resources.</td>
</tr>
<tr>
<td>Flow Effects</td>
<td>Potential impacts of an option on water flow, based on implementation.</td>
</tr>
<tr>
<td>Implementation</td>
<td>The ability of an option to be constructed in a timely manner in response to the need to deter emigrating or moving salmonids.</td>
</tr>
<tr>
<td>Operation and Maintenance</td>
<td>The effort required to keep an option operating and maintained.</td>
</tr>
<tr>
<td>Predation Effects</td>
<td>The effects of an option on predation beyond that which would occur naturally.</td>
</tr>
<tr>
<td>Tidal Effects</td>
<td>The effects of tidal stage variations as well as reverse flows on the performance of an option.</td>
</tr>
<tr>
<td>Uncertainties</td>
<td>The uncertainties associated with an option.</td>
</tr>
<tr>
<td>Upstream Migration</td>
<td>The effects of an option on the upstream migration of fish that should not be deterred.</td>
</tr>
</tbody>
</table>

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.
This page intentionally left blank.
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 Boondox dock upstream from the point of divergence 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 (Figure 4-1). 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. 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.
Figure 4-1. **Alignment of the Proposed BAFF at Georgiana Slough (in black) and Recent Study Alignments (in red)**

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 4-1). 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 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.
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 4-2). 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 or construction vessel with a very large draft required passage, a 100-foot section of the BAFF could be temporarily removed.

---

Figure 4-2. 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 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 maximize deterrence, a barrier should shift the horizontal fish distribution across 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 4-2), 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 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. Also, the existing natural flow split would remain the same. Some minor eddies and changes in flow direction may occur near the piles and frames, but the potential impacts resulting from these changes would be minor.
The tidal influences on water velocity, flow direction, and stage would have minimal effects on the BAFF’s performance. 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. 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 in-water work by divers to disconnect/connect the BAFF frames and boat or shore mounted cranes to lift the frames from/into the water. The 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. The air supply compressor system is expected to require the most preventative maintenance and greatest inspection frequency. 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 salmon emigration periods as required 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 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. No special habitat is known to exist where the BAFF system would be installed.

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.

**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 influence that a BAFF installation may have on the existing conditions is difficult to predict. Baseline densities of piscivorous fish, avian, and aquatic mammal predators are not known for this area, and thus determining the potential impacts of the BAFF on predators is not possible. Baseline densities would be established for this area before an engineering option is installed. Follow-up monitoring would take place after installation to determine the extent of potential predation effects.
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 Boondox dock upstream from the point of divergence and would terminate in the Sacramento River just beyond the divergence point. The barrier would cross the streamline 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 operation resulting from changing hydraulic conditions. 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 NMFS. See Appendix B for detailed drawings of the FFGS at Georgiana Slough.

Alignment

This barrier option would be designed to guide fish across the critical streamline, 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 4-3). 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 streamline, 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 4-3) 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.
Figure 4-3. Plan View of the Proposed FFGS at Georgiana Slough, Showing Angle-to-Flow, Vertex, and Point of Divergence

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). In rare incidences, 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 incidences currently is difficult to predict.

**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 4-4). 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 purposes. This type of boat passage system would be operated around the clock. 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.
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 beyond the critical streakline, minimizing the opportunity to swim across the current and pass through the opening. The barrier would also be slightly angled back toward the left bank at this point. This would be done to create a longer swim distance and take advantage of the fish’s swimming disadvantage versus the current.

The reasons for using a BAFF as the boat passage solution are twofold. A non-physical barrier would be necessary to have 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 4-5). The BAFF 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.

**Figure 4-5.** 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 in the recent past. Some studies show deterrence efficiencies to be between 53 and 92 percent (Scott 2011), but none were completed in an 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 primarily 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 4-6). 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 4-6.** 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 feasible to minimize these impacts.

The floats would keep the barrier at a constant 5 or 10 feet below the surface throughout all conditions. In times of low flow and low stage panels could be removed so the barrier walls 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 possible 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. If the reversing flow would happen to bring fish along with it they would encounter the barrier before they reached 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. The air supply compressor system is expected to require the most preventative maintenance and greatest inspection frequency. 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 debris 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 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 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 AECOM Engineering Evaluations
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. No special habitat is known to exist where the FFGS and BAFF systems would be installed.

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.

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.

**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 Boondox dock upstream from the point of divergence 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 angle to the flow under most hydraulic conditions. The barrier would be a series of floats that would support surface-oriented IFF units (Figure 4-7). 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.

![Image: Images Showing Two IFF Units per Pallet (left) and Example IFF Alignment with Floats and Cables (right)](source: Profish Technologie 2014)

**Figure 4-7.** 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 4-8). 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.

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 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 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). In rare incidences, 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 incidences is currently difficult to predict.
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 4-9). 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. This type of boat passage system would be operated around the clock.

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 in the water column, which would 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.
Figure 4-9. Elevation View of the Proposed 875-foot-long IFF at Georgiana Slough Including the 100-foot BAFF

**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 fish are not affected because their otoliths may not be as sensitive as they mature, but this should be tested in the field 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, 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 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 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 “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 fails 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 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 and utilities equipment and methods.
This IFF (and BAFF) could be installed reasonably quickly 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 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 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. No special habitat is known to exist where the IFF and BAFF systems would be installed.

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.

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.

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 considered during the gate selections.

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 4-10). 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 location in Georgiana Slough. The gates would provide two feet of freeboard over the highest stage on record.

Boat Passage

Boat passage is considered in this conceptual design by incorporation of a boat lock. The boat lock would be 20 feet wide and 100 feet long, and would accommodate most recreational boats. Passage of vessels larger in width will require the use of two or more 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 feasible from an engineering perspective, 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 pumps). 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 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. No special habitat is known to exist where the gate would be installed.

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.

**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.

**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 4-11). 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 an off-site storage facility and re-installed before the juvenile salmonid migration period or as agreed on with the regulatory agencies. See Appendix B for detailed drawings of the BAFF at the 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 4-11 and Figure 4-12). 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.

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 4-12 and 4-13). 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.
Figure 4-12. Elevation View of the Alignment of the Proposed BAFF at Threemile Slough (Stations 0+00 through 14+00)

Figure 4-13. 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 4-12 and 4-13).

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 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. No special habitat is known to exist where the BAFF system would be installed.

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.
**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. However, baseline densities should be established to address predation on juvenile salmonids in this area.

**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 4-14). 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 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.

**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 4-14).

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 4-15). 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.

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.
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 4-15 and Figure 4-16). 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.

**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.
Figure 4-16. Elevation View of the Southern Portion of the Proposed FFGS at Threemile Slough

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 4-17). 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.

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.
Figure 4-17. Detail Drawing of the Proposed FFGS at Threemile Slough, Showing the 5-foot and 10-foot Panels

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 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. No special habitat is known to exist where the FFGS and BAFF systems would be installed.

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.
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 4-18). 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.

Figure 4-18. Layout of the Proposed IFF at the Threemile Slough Divergence

Source: DWR – Bay-Delta Office 2014
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 4-7). 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 in a nearby storage facility and would be reinstalled before the juvenile salmonid migration period or as agreed on with the 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 4-19 and 4-20).

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.

![Infrasound Fish Fence - Threemile Slough](image-url)

**Source:** DWR – Bay-Delta Office 2014

**Figure 4-19.** Elevation View of the Alignment of the Proposed IFF at Threemile Slough (Stations 0+00 through 14+00)
Figure 4-20. 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 4-20). 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 unimpared 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. 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 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 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. No special habitat is known to exist where the IFF and BAFF system would be installed.

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.

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.

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 4-21). 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 4-21).

**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 4-22). 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.

**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.
Figure 4-21. Plan View of the Proposed Gate Structure at Threemile Slough
Figure 4-22. Proposed Boat Lock System for the Threemile Slough Location
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. No special habitat is known to exist where the gate would be installed.

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. 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.

**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 4-23). 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 in an on-site or off-site storage facility and would be reinstalled before the juvenile salmonid emigration period or as agreed on with regulatory agencies.
Figure 4-23.  BAFF at the HOR during the 2009 Test Period

Figure 4-23 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 4-24). 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. 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.

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 4-24). 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 4-25). 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.
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 are varied significantly. The most probable explanation for the variant is that much higher river flows existed during the 2010 study period than in 2009 and 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 (HOR 2009 and 2010 studies). 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 in-water work by divers to disconnect/connect the BAFF frames and boat or shore mounted cranes to lift the frames from/into the water. The 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. The air supply compressor system is expected to require the most preventative maintenance and greatest inspection frequency. 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 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. No special habitat is known to exist where the BAFF system would be installed.

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 issues 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.

**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 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).
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 4-26). 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 in an off-site or on-site storage facility and would be reinstalled before the juvenile salmonid emigration period or as agreed on with the regulatory agencies. See Appendix B for detailed drawings of the FFGS at the HOR.

Source: DWR – Bay-Delta Office 2014

Figure 4-26. Layout of the Proposed FFGS at the Head of Old River
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 4-26).

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 4-26). 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 4-27). No additional fish passage accommodation is proposed.

![Floating Fish Guidance Structure - Head of Old River](image)

Source: DWR – Bay-Delta Office 2014

**Figure 4-27.** 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 4-28). 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 4-28. 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 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. No special habitat is known to exist where the FFGS would be installed.

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.

**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.

**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 4-29) and is discussed in additional detail in subsection 2.2.4.1, “Physical Barriers,” “Overflow Gate.”

![Typical Obermeyer Gates Installed in the Kinta River, Perak, Malaysia](source: SamMcCoy.com 2014)
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 4-30). 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.

Figure 4-30. Proposed SDIP Gate Structure at the Head of Old River

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 4-30). 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.

**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. The air supply compressor system is expected to require the most preventative maintenance and greatest inspection frequency. 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 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. No special habitat is known to exist where the gate would be installed.

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 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.
**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 4-31). 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.

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 4-32 shows typical underflow (left) and overflow (right) gates. See Appendix B for general detail drawings of the proposed gate and boat lock structure.

**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 4-31. 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.
Figure 4-31. Proposed Head of Old River gate structure design.

Figure 4-32. Delta Cross Channel Radial Arm Gates on the left and Obermeyer Gates Installed in Kinta River, Perak Malaysia on the right.

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 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.

**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. The air supply compressor system is expected to require the most preventative maintenance and greatest inspection frequency. 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 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. No special habitat is known to exist where the gate would be installed.

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.

**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.

**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 4-33). 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 in an on-site or off-site storage facility and would be reinstalled before the juvenile salmonid migration period or as agreed on with the regulatory agencies. See Appendix B for detailed drawings of the BAFF at the Turner Cut.

---

**Figure 4-33. Layout of the Proposed BAFFs at Turner Cut**

Source: DWR – Bay-Delta Office 2014

AECOM Engineering Evaluations 4-62

Department of Water Resources - Bay Delta Office

Phase II Recommended Solutions Report
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 4-34 and Figure 4-35). 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 4-34 and Figure 4-35).

![Figure 4-34. Elevation View of the Proposed East Channel BAFF Alignment](source)
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 4-34 and Figure 4-35). 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 in-water work by divers to disconnect/connect the BAFF frames and boat or shore mounted cranes to lift the frames from/into the water. The frames would then be transported and stored at either an on-site or off-site storage area.

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. The air supply compressor system is expected to require the most preventative maintenance and greatest inspection frequency. 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 salmon emigration periods as required 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 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. No special habitat is known to exist where the BAFF system would be installed.

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.
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 4-36). 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 in an on-site or off-site storage facility and would be reinstalled before the juvenile salmonid emigration period or as agreed on with the regulatory agencies. See Appendix B for detailed drawings of the FFGS at the 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 4-37).
Figure 4-36. Layout of the Proposed FFGS at Turner Cut

Figure 4-37. 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 4-38). 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.

---

**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 4-37). 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 4-39). 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.

**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 at either an on-site or off-site storage area.
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 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 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.

Figure 4-39. Detailed Drawing of the 5-foot and 10-foot FFGS Panels
**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. No special habitat is known to exist where the FFGS and BAFF systems would be installed.

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.

**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.

**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 4-40). 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 in an on-site or off-site storage facility and would be reinstalled after the juvenile salmonid emigration period or as agreed on with the regulatory agencies.

Source: DWR – Bay-Delta Office 2014

Figure 4-40. Layout of the Proposed IFF at Turner Cut

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 4-41). The East and West channel barriers would each require five piles.
Figure 4-41. 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 4-41). 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 e migration 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 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 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. No special habitat is known to exist where the IFF and BAFF systems would be installed.

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.

**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.

**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 4-42). 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 4-42. 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 4-42 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 4-43). 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.
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 green sturgeon, adult salmon, and other fish and aquatic wildlife species. 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 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. No special habitat is known to exist where the gate would be installed.

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.

**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.

**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 4-44). 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.

![Bio-Acoustic Fish Fence @ Columbia Cut](images/bio_acoustic_fish_fence_columbia_cut.png)

Source: DWR – Bay-Delta Office 2014

**Figure 4-44. BAFF Alignment at Columbia Cut**

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 in an on-site or off-site 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 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 4-44). 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.

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 4-45). 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.

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 in-water work by divers to disconnect/connect the BAFF frames and boat or shore mounted cranes to lift the frames from/into the water. The frames would then be transported and stored at either an on-site or off-site storage area.

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. The air supply compressor system is expected to require the most preventative maintenance and greatest inspection frequency. 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 salmon emigration periods as required 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 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. No special habitat is known to exist where the BAFF system would be installed.

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.

**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 4-46). 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 in an on-site storage facility and would be reinstalled before the juvenile salmonid migration period or as directed by the regulatory agencies. See Appendix B for detailed drawings of the FFGS at the Columbia Cut.

Source: DWR – Bay-Delta Office 2014

Figure 4-46. Plan View of the FFGS at 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 4-44).

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 4-47). 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.

![Floating Fish Guidance Structure @ Columbia Cut](image)

Source: DWR – Bay-Delta Office 2014

**Figure 4-47. Elevation View of Both Channels**
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 4-46). 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.

**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 4-48). 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.

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 at either an
on-site or off-site storage area.

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 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 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. No special habitat is known to exist where the FFGS
and BAFF systems would be installed.

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.

**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.

**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 4-7), 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.

**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 4-49). 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).

**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 4-49).
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 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 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. No special habitat is known to exist where the IFF and BAFF systems would be installed.

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.

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.

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 4-50). 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).
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.

![Gates with Boat Lock & Fish Ladder @ Columbia Cut](image)

**Figure 4-50. Plan View of the Gates, Vertical Slot Fish Ladder, and Boat Lock**

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 4-51). 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 4-50). 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.
Figure 4-51. 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 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. No special habitat is known to exist where the gate would be installed.

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.

**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.

**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>
<thead>
<tr>
<th>Table 5-1. WRAM Relative Importance Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Criterion</strong></td>
</tr>
<tr>
<td>Boat passage</td>
</tr>
<tr>
<td>Cost</td>
</tr>
<tr>
<td>Deterrence ability</td>
</tr>
<tr>
<td>Environmental impacts</td>
</tr>
<tr>
<td>Flow effects</td>
</tr>
<tr>
<td>Implementability</td>
</tr>
<tr>
<td>Operation and maintenance</td>
</tr>
<tr>
<td>Predation effects</td>
</tr>
<tr>
<td>Tidal effects</td>
</tr>
<tr>
<td>Uncertainties</td>
</tr>
<tr>
<td>Upstream migration</td>
</tr>
</tbody>
</table>

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., IFF was the only option not considered at the Head of Old River site) 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

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Georgiana Slough</th>
<th>Head of Old River</th>
<th>Criteria</th>
<th>Three Mile Slough</th>
<th>Turner Cut</th>
<th>Criteria</th>
<th>Columbia Cut</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BAFF</td>
<td>FFGS</td>
<td>IFF</td>
<td>Gate</td>
<td>BAFF</td>
<td>FFGS</td>
<td>IFF</td>
</tr>
<tr>
<td>Boat Passage</td>
<td>0.42</td>
<td>0.31</td>
<td>0.28</td>
<td>0.00</td>
<td>0.39</td>
<td>0.33</td>
<td>0.14</td>
</tr>
<tr>
<td>Cost</td>
<td>0.19</td>
<td>0.47</td>
<td>0.33</td>
<td>0.00</td>
<td>0.33</td>
<td>0.30</td>
<td>0.14</td>
</tr>
<tr>
<td>Deterrence Ability</td>
<td>0.25</td>
<td>0.08</td>
<td>0.17</td>
<td>0.50</td>
<td>0.19</td>
<td>0.08</td>
<td>0.33</td>
</tr>
<tr>
<td>Environmental</td>
<td>0.31</td>
<td>0.42</td>
<td>0.28</td>
<td>0.00</td>
<td>0.36</td>
<td>0.47</td>
<td>0.08</td>
</tr>
<tr>
<td>Flow Effects</td>
<td>0.36</td>
<td>0.28</td>
<td>0.36</td>
<td>0.00</td>
<td>0.44</td>
<td>0.35</td>
<td>0.06</td>
</tr>
<tr>
<td>Implementability</td>
<td>0.25</td>
<td>0.36</td>
<td>0.22</td>
<td>0.17</td>
<td>0.28</td>
<td>0.33</td>
<td>0.19</td>
</tr>
<tr>
<td>O &amp; M</td>
<td>0.17</td>
<td>0.50</td>
<td>0.14</td>
<td>0.19</td>
<td>0.19</td>
<td>0.50</td>
<td>0.14</td>
</tr>
<tr>
<td>Predation Effects</td>
<td>0.26</td>
<td>0.22</td>
<td>0.29</td>
<td>0.03</td>
<td>0.21</td>
<td>0.33</td>
<td>0.14</td>
</tr>
<tr>
<td>Total Effects</td>
<td>0.22</td>
<td>0.11</td>
<td>0.17</td>
<td>0.50</td>
<td>0.17</td>
<td>0.11</td>
<td>0.36</td>
</tr>
<tr>
<td>Uncertainties</td>
<td>0.39</td>
<td>0.22</td>
<td>0.08</td>
<td>0.31</td>
<td>0.25</td>
<td>0.14</td>
<td>0.31</td>
</tr>
<tr>
<td>Upstream Migration</td>
<td>0.28</td>
<td>0.39</td>
<td>0.33</td>
<td>0.00</td>
<td>0.36</td>
<td>0.36</td>
<td>0.14</td>
</tr>
</tbody>
</table>

### Legend (values)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boat Passage</td>
<td>Least Impact (easier passage)</td>
</tr>
<tr>
<td>Cost</td>
<td>Least Impact (less cost)</td>
</tr>
<tr>
<td>Deterrence Ability</td>
<td>Most Benefit (better deterrence)</td>
</tr>
<tr>
<td>Environmental</td>
<td>Least Impact (less environmental impacts)</td>
</tr>
<tr>
<td>Flow Effects</td>
<td>Least Impact (less flow impacts)</td>
</tr>
<tr>
<td>Implementability</td>
<td>Most Benefit (easier seasonal installation)</td>
</tr>
<tr>
<td>O &amp; M</td>
<td>Most Benefit (easier O&amp;M)</td>
</tr>
<tr>
<td>Predation Effects</td>
<td>Least Impact (less predation)</td>
</tr>
<tr>
<td>Total Effects</td>
<td>Least Impact (less performance impacts)</td>
</tr>
<tr>
<td>Uncertainties</td>
<td>Least Impact (less uncertainty)</td>
</tr>
<tr>
<td>Upstream Migration</td>
<td>Least Impact (less migration impacts)</td>
</tr>
</tbody>
</table>
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 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>
<thead>
<tr>
<th>Site</th>
<th>Option</th>
<th>BAFF</th>
<th>FFGS</th>
<th>IFF</th>
<th>Gate</th>
<th>SDIP Gate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Georgiana Slough</td>
<td></td>
<td>0.29</td>
<td>0.28</td>
<td>0.25</td>
<td>0.18</td>
<td>NA</td>
</tr>
<tr>
<td>Three mile Slough</td>
<td></td>
<td>0.29</td>
<td>0.28</td>
<td>0.26</td>
<td>0.17</td>
<td>NA</td>
</tr>
<tr>
<td>Head of Old River</td>
<td></td>
<td>0.29</td>
<td>0.30</td>
<td>NF</td>
<td>0.21</td>
<td>0.19</td>
</tr>
<tr>
<td>Turner Cut</td>
<td></td>
<td>0.31</td>
<td>0.28</td>
<td>0.28</td>
<td>0.13</td>
<td>NA</td>
</tr>
<tr>
<td>Columbia Cut</td>
<td></td>
<td>0.30</td>
<td>0.28</td>
<td>0.28</td>
<td>0.13</td>
<td>NA</td>
</tr>
</tbody>
</table>

Notes: 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, Three mile Slough, Turner Cut, and Columbia Cut**: BAFF, FFGS, IFF, and Gate (Franks Tract Gate at Three mile 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 added, multiplied, and divided 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 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, 2012 and 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, much time has been spent researching technologies to consider engineering solutions 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, the IFF also shows promise theoretically to deter juvenile salmonids.

The importance of understanding the hydrodynamics at each of the junctions became clearer with data collection and analysis that was performed with each of the field studies. The complexities of tidal effects and testing during limited range of flows made assessing the performance of an option over the full range of flows very expected challenging.

6.2  CONSTRAINTS AND UNKNOWNS

During the past 5 years, a large effort was invested into researching and field testing technologies identified in the Phase I report. There are still unknowns that exist to fully understand how effective each of the technologies would perform over the full range of flows if constructed. Untested engineering technologies, better understanding of hydrodynamic interactions with engineering technologies, specific gate operations, and piscivorous predation interactions with the engineering technologies could be better understood.

Unfortunately, unlimited resources and time are not available to eliminate all of the identified uncertainties.

6.2.1  TRANSPORTATION (TRUCKING AND BARGING)

Implementation of an engineering technology at each of the 5 junctions is the goal for Phase III of the Action. If NMFS deems that none of the options presented in this report would be viable, implementing transportation of juvenile salmonids downstream by trucking or barging is another consideration. In 2014, juvenile salmonids were trucked and released near Chipps Island in hopes of increased survival due to the extreme drought conditions that occurred. The preference is to have juvenile salmonids naturally emigrate in the Sacramento and San Joaquin rivers with the assistance of an engineering technology.

6.3  ADDITIONAL RESEARCH AND MONITORING FOR CONSIDERATION

In moving forward to implement options in Phase III at each of the junctions addressed in this report, additional research and monitoring should be considered. A few items to consider are:

► Review of current studies related to the Action when they are completed;

► Additional field study of an FFGS pending results from the 2014 study;

► Field study of an IFF to determine deterrence ability;
► Modeling of specific gate operations for the gate options;
► Additional hydrodynamic modeling coinciding with field studies to observe engineering technology performance;
► Implement ELAM modeling of technologies at the junctions when the model is fully developed;
► Additional tagged fishes 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.

6.4 ONGOING STUDIES AND ANALYSES

The 2014 FFGS study and ELAM model are currently being analyzed and developed, thus weren’t available at the time of this report release. Both the FFGS and ELAM have direct information related to the assessment of engineering technologies that are 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 were only completed for 2 technologies at 2 junctions.

In addition, multiple other on-going studies may provide useful future information and should be considered in possibly re-evaluating the WRAM assessments when the analyses become available.

6.5 ADAPTIVE MANAGEMENT IMPLEMENTATION

Potential engineering solutions for the interior and south Delta that are implemented at one of more of the five sites reviewed in this report will be subject to an adaptive management and monitoring program. This program will include the latest and newest information and insight gained during the course of a specific engineering treatment to help develop and potentially implement alternative strategies to achieve the biological goals and objectives identified in the NMFS BO (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 salmonid are present in the target areas where survival has been shown to be lower than other areas.

Compliance monitoring will consist of documenting the installation and operation of engineered fish barriers. Effectiveness monitoring will consist of assessing the effectiveness of each barrier, including the pilot testing now under way in the Delta (e.g., Georgiana Slough). DWR will use results from effectiveness monitoring to determine whether operations 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 employed to determine the differences in effectiveness.

Table 6-1 provides potential monitoring actions, metrics, success criteria, and timing and duration for monitoring. These monitoring elements may be modified, as necessary, to best assess the effectiveness of any given treatment, based on the best available information at the time of implementation.

<table>
<thead>
<tr>
<th>Monitoring Action</th>
<th>Metric</th>
<th>Success Criteria</th>
<th>Timing and Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site-level Assessment</td>
<td>Migration</td>
<td>Monitor the effectiveness of fish barriers in deterring juvenile salmonids from migrating into interior Delta and other waterways known to result in reduced survival</td>
<td>Annually for 5 years beginning at permit authorization, reevaluating monitoring needs after year 5</td>
</tr>
</tbody>
</table>

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 will be implemented through the adaptive management decision-making process, and through subsequent annual work plans.

<table>
<thead>
<tr>
<th>Key Uncertainties</th>
<th>Potential Research Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>How effective are barriers over the long-term?</td>
<td>• Evaluate change in survivorship of juvenile salmonids.</td>
</tr>
<tr>
<td></td>
<td>• Evaluate effectiveness of barriers in high-flow areas.</td>
</tr>
<tr>
<td></td>
<td>• Monitor changes in proportion of juvenile salmonid distribution and abundance upstream and downstream of barrier.</td>
</tr>
<tr>
<td></td>
<td>• Evaluate behavioral response(s) of juvenile salmonids to barriers.</td>
</tr>
<tr>
<td></td>
<td>• Evaluate the effectiveness and permeability of barriers with studies using tagged juvenile salmonids.</td>
</tr>
<tr>
<td>How do barriers affect predators?</td>
<td>• 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.</td>
</tr>
<tr>
<td></td>
<td>• Evaluate effectiveness of deterrents on green sturgeon, steelhead, and Chinook salmon.</td>
</tr>
<tr>
<td></td>
<td>• Evaluate potential attraction of piscivorous predators to fish barriers (e.g., type/species and number).</td>
</tr>
<tr>
<td></td>
<td>• Evaluate the extent of piscivorous predator aggregation at barriers before and after installation.</td>
</tr>
<tr>
<td></td>
<td>• Evaluate piscivorous predator composition before and after installation of barriers.</td>
</tr>
<tr>
<td></td>
<td>• Evaluate piscivorous predator response to operation of barriers.</td>
</tr>
</tbody>
</table>

In applying adaptive management principals to the evaluation of engineering solutions the practicality of the goal of the NMFS BO (2009) of reducing entrainment into the interior and south Delta at the 5 locations reviewed can be evaluated.
This page intentionally left blank.
7 REFERENCES


California Department of Fish and Game. 1996. Steelhead Restoration and Management Plan for California. Inland Fisheries Division, California Department of Fish and Game, Sacramento, CA.


2013b (December 9). *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*.


CDFW. See California Department of Fish and Wildlife.


DFG. See California Department of Fish and Game.


DWR. See California Department of Water Resources.

DWR and Reclamation. See California Department of Water Resources and U.S. Bureau of Reclamation.

Environmental Protection Information Center, Center for Biological Diversity, and WaterKeepers Northern California. 2001. Petition to List the North American Green Sturgeon as an Endangered or Threatened Species under the Endangered Species Act.


EPRI. See Electric Power Research Institute.


GCID. *See Glenn Colusa Irrigation District.*


Kennedy, Trevor. Fisheries Biologist. Fishery Foundation of California, Elk Grove, CA. July 2011—e-mail to Steve Pagliughi of AECOM, transmitting 2011 data pertaining to the number of trucked juvenile salmonids received at the San Pablo Bay release location.


Moyle, P. B., J. E. Williams, and E. D. Wikramanayake. 1989. Fish Species of Special Concern of California. Final report submitted to the Inland Fisheries Division, California Department of Fish and Game, Rancho Cordova, CA.


Moyle, P. B., R. M. Yoshiyama, J. E. Williams, and E. D. Wikramanayake. 1995. Fish Species of Special Concern in California. Second edition. Inland Fisheries Division, California Department of Fish and Game, Rancho Cordova, CA.


———. 2011a. 5-Year Review: Summary and Evaluation of Sacramento River Winter-Run Chinook Salmon ESU. Southwest Region, Long Beach, CA.

———. 2011b. 5-year review: Summary and Evaluation of Central Valley Steelhead DPS. Southwest Region, Long Beach, CA.


NMFS. See National Marine Fisheries Service.


Reclamation. See U.S. Bureau of Reclamation.


Sand, O., and H. E. Karlsen. 1986. Detection of Infrasound by the Atlantic Cod.


Scott, S. 2011. *A Positive Barrier Fish Guidance System Designed to Improve Safe Downstream Passage of Anadromous Fish*.

Shapovalov, L. and A. C. Taft. 1954. *The Life Histories of the Steelhead Rainbow Trout (Salmo gairdneri gairdneri) and Silver Salmon (Oncorhynchus kisutch) with Special Reference to Waddell Creek, California, and Recommendations Regarding Their Management*. California Department of Fish and Game Fish Bulletin No. 98.


USACE. See U.S. Army Corps of Engineers.


———. 2009a (April). Guidelines for Performing Hydraulic Field Evaluations at Fish Screening Facilities.


USFWS. See U.S. Fish and Wildlife Service.


Meeting Date/Time: 07/07/2011, 2:00pm – 4:00pm (PST)

Participants:
Mark Holderman, DWR  Daniel Kratzville, CDFG (phone)
Jacob McQuirk, DWR  Maral Kasparian, USFWS (phone)
Josh Israel, USBR  Khalid Ameri, DWR
Ryan Reeves, DWR  Jeff Stuart, NMFS
George Heise, CDFG  Bill McLaughlin, DWR
Bob Pedlar, DWR  Josh Brown, DWR

Meeting Summary:

1. Purpose of Call

The primary purpose of the meeting was to discuss the draft table of contents for the report that Josh provided and to discuss/brainstorm options to be considered for all sites to further reduce diversion of emigrating juvenile salmonids. Also, to discuss performance objectives of the options that will be considered.

2. Discussion on the draft table to contents

BM: Introduced meeting topics, June 16th TWG meeting summary, and overall intent of the meeting.

JM: Suggested adding a flow/hydraulics section.

There were no major comments on the outline at this moment. However, detailed comments will be provided to Josh prior to the next TWG meeting. Josh discussed the ELAM model used on the Columbia River (provided documents through e-mail). He added that this model will be beneficial in validating fish behavior. Also, there was concern whether there is enough hydrodynamic data to run the ELAM model.

3. Option Brainstorming

A floating buoy fish barrier was introduced which is currently used at the Bonneville Dam on the Columbia River to direct migrating salmon away from the intakes. It’s was noted that this type of structure might only work effectively in low flow environment. George will provide us with more detailed information regarding this type of barrier.
GH: Suggested to consider partially blocking the channel. For example Head of Old River; instead of having a 50/50 split we could reduce the split to 80/20. By achieving this we will be able to keep fish in the main channel. However, this option might work only at the HOR and not at other locations.

BM: Talked about the DSM2 hydrodynamic data analysis at a few of the project sites, since there is insufficient observed historical data available. Preliminary DSM2 hydraulic data analysis results will be available to the group prior to the next TWG meeting.

JS: Suggested consideration of behavioral-systems in combination with physical barrier. Also mentioned that NMFS Seattle office as having some experience with tidally influenced estuaries.

JI: Suggested to consider independent science review panel members involvement earlier in the study.

GH: Discussed the electric fish ladder technology used in the Merced River. However, he was concerned that this technology might not be feasible for juvenile entrainment.

JI: Introduced an option to transport fish by using a barge to a desired location downstream. This method is used in the Columbia River to increase returns of fish to the hatchery. In order for this option to work effectively we need to determine when the majority of fish will be present at a specific location. All agreed that a most common downside to this option would be increased predation and capturing different type of fish species simultaneously. Jeff was concerned that the life history of fish is an important part to fish behavior, so we need to have some type of criteria in place to determine when to use this option.

JI: Discussed the benefits of randomly releasing fish rather than at specific release points.

A permanent operable gate option was also discussed.

Flow vanes/louvers should be considered.

MH: Proposed to consider flow when operations of an option are needed.

JM: Indicated that no matter what option we select, we need a lead time to properly execute that particular option. BM pointed out that having a permanent permitting option in place to execute a preferred option instead of having to go through annual permitting would have its advantages.

MK: Proposed to consider the effects on Delta smelt as one of the criteria. She also added that other species such as longfin smelt might also be listed as an endangered species by the time we are done with the study and should also be considered. The timing of barrier operations effects on Delta smelt should be considered.
4. Action Items and Next Steps

- Next TWG Meeting scheduled for 07/28/11 at 1:00pm – 3:00pm (PST)
- Provide comments on the report outline to Josh (all)
- Look into science panel involvement (Stuart)
- Provide DSM2 hydraulic data analysis at each site (McLaughlin/Ameri)
- Update list of options and criteria (McLaughlin)
- Prepare site maps for each location (McLaughlin/Brown)
- Look into available bathymetry data (McLaughlin)
- Ftp site access information (Ameri)
- Talk with Steve/Rick about draft objectives criteria (Stuart)
- Look into EPRI, contact Ned Taft (McLaughlin)
Meeting Date/Time: 08/25/2011, 10:00pm – 12:00pm

Participants:

George Heise, CDFG
Maral Kasparian, USFWS
Steve Thomas, NMFS
Jeff Stuart, NMFS

Mark Holderman, DWR
Jacob McQuirk, DWR
Bill McLaughlin, DWR
Bob Pedlar, DWR

Meeting Summary:

Franks Tract Project

The group discussed the Franks Tract Project at Three Mile Slough presented by Teresa Geimer to the group at the last meeting. Maral added that the existing project utilizing a gate could have nutrient flow concerns and possible predator concerns. It was suggested to include the additional site within the upcoming report in a narrative format.

Jeff added that NMFS is not limiting which channels are considered.

Discussion on the draft table of contents/maps

The latest draft of the table of contents sent out August 4th was discussed with no additions suggested. DWR staff will write a majority of the report with the assistance of pertinent information provided from various agencies. Draft sections of the report will be sent out beginning in September for the group to begin review.

Project Sites

DWR staff discussed a tour of the Turner and Columbia Cuts sites that were toured by DWR staff the week before. If members of the group are interested, a tour of the sites can be arranged.

Bathymetric surveys of Turner and Columbia Cuts will be planned for use in further evaluation of options at the sites. The need for further fishery information was briefly discussed but additional research needs to be completed on existing documents.
Department of Water Resources, Bay-Delta Office

Performance objectives/criteria

No additional objectives/criteria added.

Options

Maral commented that USFWS prefers flow friendly and submerged structures and that predatory behavior prevention is important.

No additional options added.

Independent Review Panel

DWR staff is still waiting to hear back from the Delta Stewardship Council (Sam Harader) to discuss forming an Independent Review Group in January 2012 to review the draft report.

Action Items and Next Steps

- Next TWG Meeting scheduled for September 15th at 10:00am – 12:00pm
- Provide feedback on the Franks Tract project (all)
- Look into science panel involvement (Pedlar/McLaughlin)
- Provide feedback on options and criteria (All)
OCAP Action IV.1.3  
Technical Working Group Meeting Summary  

Meeting Date/Time: 10/06/2011, 10:00pm – 12:00pm  

Participants:  

George Heise, CDFG  
Maral Kasparian, USFWS (phone)  
Steve Thomas, NMFS (phone)  
Jeff Stuart, NMFS  
Khalid Ameri, DWR  
Josh Brown, DWR  
Ben Geske, DWR  
Jacob McQuirk, DWR  
Bill McLaughlin, DWR  
Bob Pedlar, DWR  
Josh Israel, USBR  
Ryan Reeves, DWR  

Meeting Summary:  

Franks Tract Project/Other Projects  

The group discussed the Franks Tract project at Three Mile Slough. Bill indicated that the Franks Tract project should be at least briefly discussed in the phase I report if not as an option.  

Josh Israel added that the Yolo Bypass fish passage projects, BDCP, and other projects that may potentially have an effect on our study should also be discussed in the report. The various life cycle and passage models that are currently being developed will be extremely helpful in assisting with investigating engineering solutions under this particular OCAP action.  

Discussion on the Report Write-Ups  

Bill requested comments on the site description and species of interest write-ups form the group. A request for a San Joaquin River migration table and chart to be included in the species of interest section was made. DWR staff will write a majority of the report with the assistance of pertinent information provided from various agencies. The draft report will be completed by November 15th for the group to review.  

Science Panel Review  

Bill added that after discussing with the Delta Stewardship Council, a science review panel will not be available to review the draft report in January 2012. A different independent science panel will need to be sought to review the report. The group will send contact information to Bill of possible candidates to structure a new Independent review panel. The goal is to have the panel review the report by January 2012.
Bathymetric Surveys/Other Data Source

Bill added that bathymetric surveys for use in further evaluation of options at Turner and Columbia Cuts will be completed sometime before the end of June 30, 2012.

There is a concern that there is limited fish survival or fish behavioral data available. Essential data that is being processed and analyzed from the VAMP and six year studies will be helpful. Additional information may be needed in the future.

Action Items and Next Steps

- Next TWG Meeting scheduled for November 10th at 10:00am – 12:00pm.
- Additional draft sections of the report will be sent out in the coming weeks.
- Provide feedback on developed sections of the report (all).
- Look into creating a new science review panel (all).
Meeting Date/Time: 11/10/2011, 10:00pm – 12:00pm

Participants:

George Heise, CDFG  
Maral Kasparian, USFWS  
Steve Thomas, NMFS (phone)  
Jeff Stuart, NMFS  
Khalid Ameri, DWR  
Josh Brown, DWR  
Ben Geske, DWR  
Jacob McQuirk, DWR  
Bill McLaughlin, DWR  
Bob Pedlar, DWR  
Josh Israel, USBR (Phone)  
Ryan Reeves, DWR

Meeting Summary:

Discussion on the Phase I Draft Report

The group discussed the preliminary draft Phase I report and Bill requested comments on the report from the group. Jeff will provide the San Joaquin River migration table and the table will be added to the species of interest section of the report. The most complete draft report with TWG review will be completed by December 16th.

Science Panel Review

Independent science panel formation is still ongoing. Bill will screen possible candidates to structure the Independent review panel. The goal is to have the panel review the report by end of February 2012. Josh Israel proposed to have at least one fish Behaviorist on the panel. Bill proposed to form one Independent science panel to review both the Phase I draft report and the 2011 Georgiana Slough Non Physical Barrier study report.
Franks Tract Project/Other Projects

Bill showed concerns how the Franks Tract project should be discussed in the Phase I report. It was pointed out that to add the Franks Tract project in our report as an ongoing project that may potentially have an effect on the OCAP study.

Action Items and Next Steps

- Provide feedback and comments on the preliminary draft Phase I report (all).
- The most complete draft report will be sent out by December 16th, 2011.
- Look into creating a new science review panel.
- Next TWG Meeting will be scheduled in January, 2012 at the time the full draft is provided to the group in December.
OCAP Action IV.1.3  
Technical Working Group Meeting Summary

Meeting Date/Time: 08/21/2012, 1:00pm – 3:00pm

Participants:

Chad Dibble, CDFG  
Maral Kasparian, USFWS  
Jason Roberts, CDFG  
Jeff Stuart, NMFS  
Bill McLaughlin, DWR  
Khalid Ameri, DWR  
Ben Geske, DWR  
Jacob McQuirk, DWR  
Bob Pedlar, DWR  
Josh Israel, USBR  
Michael Eakin, CDFG  
Ryan Reeves, DWR  
Mark Holderman, DWR  
Josh Brown, DWR
Discussion on the Science Advisory Review of the Phase I Draft Report

Bill McLaughlin (BM) kicked-off the meeting and introduced meeting participants. BM stated that the purpose of the meeting was to discuss the phase I report Science Advisory Review panel comments and obtain input and comments from the Technical Working Group prior to finalizing the document.

Comment 4PS (pg 2) Discussion:
Jeff Stuart indicated that any action we take needs to work in harmony with other OACP actions. Jacob McQuirk added that due to limited available tools, it would be difficult if not impossible to achieve the system-wide analysis goal by the 2015 deadline. Josh Israel added that various life cycle and passage models, that are currently being developed, will be extremely helpful in assisting with investigating engineering solutions under this particular OCAP action at each location. BM showed concern that the deadline is fast approaching and it would not be possible to embrace system-wide analysis.

Jeff Stuart provided explanation of the intent of BO Action IV.1.3 language. It was confirmed that the action’s intent is to perform engineering evaluation to identify technologies/alternatives at individual sites by 2015 deadline. Josh Israel pointed out that it’s not clear whether we are going to adopt the CEQA/NEPA process during the 2nd phase of the report. It was agreed that the CEQA/NEPA process is not going to be achieved by the 2015 deadline; however, it will be acknowledged in the phase II report that the CEQA/NEPA process will occur after the phase II report is completed.

Maral Kasparian asked if the options we are considering will be supported by some type of data analyses. Bill added that some data analyses and conceptual designs will be part of the option screening in the phase II report and our main focus will be to determine fish deterrence ability, flow neutrality, upstream migration, and boat passage concerns for all options.

Comment 5P (pg 4) Discussion:
Josh Israel suggested that agencies should provide us with a number for determining what percentage for deterrence efficiency is expectable for a specific technology, and we need to have a clear objective that is quantifiable. Jeff Stuart acknowledged the need for a measurable deterrence goal for each junction and technology, and he affirmed that agencies will work on that. It was also agreed that the intent of this action is not to control predation, but we can’t contribute to the existing predation issues at each site by considering any option.

Comment 22P (pg 9) Discussion:
Maral Kasparian suggested that if we decide to select habitat restoration for a specific site as an option, we need to know what impact it’s going to have on other species habitat at each junction. It was also agreed upon to concentrate only on the single channels at Turner and Columbia Cuts.
Department of Water Resources, Bay-Delta Office

Comment 12R (pg 16) Discussion:
BM asked if using hatchery fish for our study is going to be concern. Jeff Stuart indicated that this issue has been raised before and there is no plan B to consider, since it’s not possible to tag wild fish.

Comment 3S (pg 12) Discussion:
BM asked if we need to look into different routes for fish migration even though it’s clearly not part of the action. Jeff Stuart indicated that fish survivability is much higher in Steamboat and Sutter Sloughs; however, we are not asked to look into those junctions as part of this action.

Comment 4P (pg 4) Discussion:
It was agreed upon to add the detailed information about fish species in the appendix of the phase I report instead of having it in the main report.

Other Concerns

Maral Kasparian suggested updating some of the citations in the phase I report prior to finalizing the report, since some referenced material were already published or issued as we were preparing the draft report. She also requested that we include additional facts on the delta smelt in the report.

Chad Dibble suggested that we clearly state in the Phase I report when a particular discussion will be revisited in further detail in the Phase II report.

Action Items and Next Steps

- Provide feedback and comments on the Science Advisory Review of the Phase I Draft Report by COB August 24th, 2012 (all).
- Next TWG Meeting will be scheduled in September, 2012 at the time initial option screening process will be discussed.
- A copy of the WRAM, and Bob Pedlar’s review/summary of the WRAM, will be emailed to the group for review. (Bill McLaughlin)
Meeting Date/Time: 12/20/2012, 10:00am – 12:00pm

Participants:
- Maral Kasparian, USFWS
- Jeff Stuart, NMFS (phone)
- Bill McLaughlin, DWR
- Khalid Ameri, DWR
- Ben Geske, DWR
- Josh Israel, USBR (phone)
- Michael Eakin, CDFG
- Ryan Reeves, DWR
- Mark Holderman, DWR
- Josh Brown, DWR
- George Heise, CDFG
- Steve Thomas, NMFS (phone)
- Teresa Geimer, DWR (phone)
**Meeting Summary:**

Bill McLaughlin kicked-off the meeting and introduced meeting participants. He stated that the purpose of the meeting was to discuss some of the engineering options that we are considering further and to see if we are able to eliminate some of the unrealistic options.

A PowerPoint presentation was given on the initial screening of the options. The group discussed some of the advantages and disadvantages associated with each option. Also some conceptual drawings of the considered options were shown.

Josh Israel commented on the non-physical options being flow neutral. He indicated that a non-physical barrier might be flow neutral regionally, but not locally. Josh would like to see the mechanics of fish behavior being considered with any of the options.

George Heise pointed out that having a full column fish screen might not be feasible due to adult fish migration. He suggested an alternative to consider is to have a partial column screen instead of having a full column screen which will allow passage for adult fish.

The group suggested considering the use of screen panels for the floating guidance walls instead of solid panels. One of the main issues with screening the panels is debris which will eventually clog the screens. Suspended louvers were brought up as an alternative to screen plates.

Bill asked the group if anyone felt strongly about eliminating any options from consideration. It was agreed among the group to eliminate the electric barrier option due to not being able to specifically target species of concern without affecting other fish species and public safety issues. Michael Eakin would like to see more information regarding the electrical barriers. Ben Geske will provide him with the research that has obtained.

A discussion was held regarding some details about the infrasound barrier. Topics covered include the zone of influence produced by the technology, description of the mechanism that produces the infrasound, the theory surrounding why and how the infrasound (particle acceleration) triggers a behavioral response in small fish, possible constraints for deployment at some or all of the sites, and specific questions to research further and report back to the group. It was decided that further research on topics raised would take place between now and the next meeting where Ben Geske will provide a presentation explaining the new findings and other additional details regarding the infrasound barrier technology.

Bill also asked the group if we needed to look into eliminating a new rock barrier as an option. It was pointed out that instead of having a rock barrier it would be better to have some type of engineered structure which could do the same job as a rock barrier. An engineered structure would be more cost effective and work in most of the flow conditions. The TWG was agreeable to dropping a rock barrier as an option.

The next TWG Meeting will be scheduled in mid February, 2013.

**Action Items and Next Steps**

- Develop the conceptual drawings further to show some of the hybrid options. (Bill McLaughlin)
- At the next TWG meeting we will discuss the Water Resources Assessment Methodology (WRAM) method used for scoring the options in the Phase II report. (All)
- A presentation covering more detailed information about the infrasound technology will be given at the next TWG meeting. (Ben Geske)
OCAP Action IV.1.3

Technical Working Group Meeting Summary

Meeting Date/Time: 02/13/2013, 1:00pm – 3:00pm

Location: DWR HQ in Room 241 and (Conference Call)

**Participants:**

<table>
<thead>
<tr>
<th>Name</th>
<th>Agency/Office</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ben Geske, DWR</td>
<td></td>
</tr>
<tr>
<td>Bill McLaughlin, DWR</td>
<td></td>
</tr>
<tr>
<td>Bob Pedlar, DWR</td>
<td></td>
</tr>
<tr>
<td>George Heise, CDFW</td>
<td></td>
</tr>
<tr>
<td>Jeff Stuart, NMFS (phone)</td>
<td></td>
</tr>
<tr>
<td>Josh Brown, DWR</td>
<td></td>
</tr>
<tr>
<td>Khalid Ameri, DWR</td>
<td></td>
</tr>
<tr>
<td>Krystal Acierto, CDFW</td>
<td></td>
</tr>
<tr>
<td>Maral Kasparian, USFWS</td>
<td></td>
</tr>
<tr>
<td>Mark Holderman, DWR</td>
<td></td>
</tr>
<tr>
<td>Ryan Reeves, DWR</td>
<td></td>
</tr>
<tr>
<td>Steve Thomas, NMFS (phone)</td>
<td></td>
</tr>
</tbody>
</table>
Meeting Summary:

Bill McLaughlin started the meeting with introductions and then briefly explained the agenda and intent of the meeting.

Ryan Reeves spoke about the possibilities of another study at Georgiana Slough in 2014. The idea of studying a floating fish guidance wall was discussed with the working group. Ryan mentioned that getting support from the TWG members was important and offered the opportunity for members to ask questions and voice their concerns. Jeff Stuart suggested an on/off, or in/out cycling of the technology similar to that of the BAFF study. George Heise brought up the idea of using some type of system to lift the walls, or move them out of the way instead of removing them from the water. This could improve the down time between on/off cycles. All of the meeting attendees were in support of the study idea/proposal. Ryan will deliver a more in depth study proposal at the next meeting, and also update the TWG members on the 2011 and 2012 GSNPB study results. Maral Kasparian mentioned that getting the study plan proposal to her prior to this summer would be beneficial due to their heavy work load and other project commitments.

Ben Geske gave a presentation on the infrasound fish guidance system as a follow up to the last meeting. The presentation included information such as the background and history of infrasound as a fish deterrent, technical aspects of the infrasound generator, the theory behind the behavioral responses induced by the propagated signal, the relevant zones of the infrasound’s influence, laboratory and field study results, and visual aids such as pictures, diagrams, and a video. Jeff was concerned whether or not this technology would adversely affect other species such as Green Sturgeon. It was agreed upon to look into the issue. George asked what the difference between particle acceleration and sound pressure was. (After the meeting, Ben was able to look over his research and give his response here in the meeting notes - Sound in water is comprised of both particle acceleration and pressure variations. Responses due to particle acceleration are related to a direct interaction between the motion of the particle and the fish’s inner ear/otolith. Sound pressure indirectly interacts with the inner ear via the swim bladder. It could also be pointed out that sound pressure is measured with a microphone/hydrophone, and particle acceleration is measured with an accelerometer). The fact that there have not been any recent field studies in the US or applications with the NMFS BiOp RPA Action IV.1.3 specific challenges such as fish species, hydraulic condition, and specific site challenges was brought up. There was a discussion regarding the uncertainties of the relatively new deterrence option and the need to possibly field test the technology came up when questions of how to answer those uncertainties arose. Ben will organize the material used in his research of the technology and place it in a shared location for the group members.

Bob Pedlar gave a presentation on the Water Resources Assessment Method (WRAM), which was developed by the Army Corps for their use in evaluating water resource project alternatives. This method will be used in the evaluation of the potential engineering solutions in order to help the TWG members weigh and score each option in comparison to each other and the action specific criteria. It was agreed among the group to review the WRAM criteria importance survey form prior to the next meeting. This would give each member time to understand the
methodology and start thinking about how they might score or weigh each of the options and criteria. A general overview of the WRAM method was also provided to the TWG members to review and become familiar with the method. It was discussed that the “Do Nothing” and “Transporting” options should not be included in the assessment since these are not “Engineering Options”.

Hydrodynamic data collection and updates on conceptual designs that were in the agenda will be discussed in the upcoming TWG meeting due to time constraints.

The next TWG Meeting will be scheduled for the 2nd week of April, 2013.

**Action Items and Next Steps**

- Send reference and previous study materials on the infrasound technology to the group. (Bill McLaughlin)
- Look into affects on Green Sturgeon. (Ben Geske)
- At the next TWG meeting Ryan Reeves will present the 2011 and 2012 BAFF results and he will also provide more details about the potential Floating Fish Guidance Wall implementation at the Georgiana Slough project site. (Ryan Reeves)
- Send out website link(s) on floating barriers to the group. (Bill McLaughlin)
- Send the Water Resources Assessment Methodology (WRAM) method criteria importance survey form to the group. (Bill McLaughlin)
- Develop the conceptual drawings further to show the other options. (Khalid Ameri/Ben Geske)
OCAP Action IV.1.3

Technical Working Group Meeting Summary

Meeting Date/Time: 04/11/2013, 1:00pm – 3:00pm

Location: DWR HQ in Room 210 and (Conference Call)

Participants

Ben Geske, DWR
Bill McLaughlin, DWR
Dave Huston, DWR
George Heise, CDFW
Jeff Stuart, NMFS
Jon Burau, USGS
Josh Brown, DWR
Kari Bianchini, DWR

Khalid Ameri, DWR
Krystal Acierto, CDFW
Maral Kasparian, USFWS
Mike Cane, DWR
Noah Adams, USGS
Russ Perry, USGS
Ryan Reeves, DWR
Steve Thomas, NMFS
Meeting Summary:

Bill McLaughlin started the meeting with introductions and then briefly explained the agenda and intent of the meeting.

Ryan Reeves spoke about the possibilities of a floating fish guidance wall study at Georgiana Slough in spring 2014.

Presentations:

“Collapsing flow field complexity in junctions: The Critical Streakline” (Jon Burau)
Jon gave a presentation on the hydrodynamics of the Sacramento River in the vicinity of Georgiana Slough. He shared an animation of hydrodynamic data collected at the junction and discussed directional flow patterns in the area. He concluded that high densities of fish are near the streakline and it may be possible to shift the fish distribution toward the Sacramento River side of the streakline in order to avoid entrainment into Georgian Slough. It was suggested that fish distribution and hydrodynamic information is critical for the placement of any type of barrier to be effective.

“Proof of Concept for Using Simple Guidance Structures to Alter Migration Routing at River Junctions” (Russ Perry)
Russ talked about fish distribution in the channel at the Georgiana Slough project site. He emphasized how much fish distribution will affect the entrainment probability.

“Overview of Fish Guidance Boom Technologies Utilized in the Pacific Northwest” (Noah Adams)
Noah gave a presentation on the floating fish guidance wall technology that was utilized in the Pacific Northwest. It was pointed out that there is limited information on how much the floating fish guidance wall will be effective in higher flows that occur in the Sacramento River. As of now this type of technology is only tested in much lower flows. Ryan purposed the idea of studying a floating fish guidance wall at the Georgian Slough in 2014. All of the meeting attendees were in support of the study idea/proposal.

Water Resources Assessment Method (WRAM) criteria ranking discussion

It was agreed among the group to review and take a first stab on the WRAM criteria ranking, and results will be discussed at the next meeting.

The next TWG Meeting will be scheduled for the end of May or the 1st week of June, 2013.

Action Items and Next Steps

- Rank the Water Resources Assessment Methodology (WRAM). (All)
- Develop the conceptual drawings further to show the other options. (Khalid Ameri/Ben Geske)
Meeting Date/Time: 06/20/2013, 1:00pm – 3:00pm

Location: DWR HQ in Room 341 and (Conference Call)

Participants

Ben Geske, DWR
Bill McLaughlin, DWR
Bob Pedlar, DWR
Colin Purdy, CDFW
George Heise, CDFW
Jacob McQuirk, DWR
Jason Roberts, CDFW

Jeff Stuart, NMFS
Josh Brown, DWR
Khalid Ameri, DWR
Krystal Acierto, CDFW
Mark Holderman, DWR
Steve Thomas, NMFS (phone)
Teresa Geimer, DWR
Meeting Summary:

Bill McLaughlin started the meeting with introductions and then briefly explained the agenda and intent of the meeting.

Presentation:

Physical Gate Option Conceptual Designs

Ben and Khalid gave a presentation on the draft physical gate deterrence options for Georgiana Slough, Head of Old River, Turner Cut, and Columbia Cut. An overflow gate (weir gate) was presented at Georgiana Slough and Columbia Cut, and an underflow gate (radial arm gate) was presented at the Head of Old River and Turner Cut. They noted that the designs are in the preliminary stage, and changes to the design will be incorporated once comments and suggestions are received from the group. Ben and Khalid mentioned that the two different gate styles could be used at any of the sites. A decision has not yet been made about what style of gate would be best suited for each individual site. Gates were placed in the junctions for the purpose of starting a discussion about the physical deterrence options.

There was a concern expressed regarding not addressing sturgeon passage as part of the physical gate conceptual designs. It was suggested that a boat lock, or a partially open radial arm gate could be used to accommodate sturgeon passage. A suggestion was made to look into some past sturgeon passage studies such as the UC Davis research on the sturgeon passage structures Steve and George suggested contacting Bob Gatton with CH2M Hill regarding a sturgeon passage ladder design at the Sack Dam on the San Joaquin River. Steve also suggested that if a similar ladder design is used, that steel removable baffles be incorporated to provide operation flexibility.

Water Resources Assessment Method (WRAM) criteria ranking discussion

There was a discussion among the group regarding the WRAM criteria ranking. No one submitted a copy of their Agency’s ranking results and DFW and USFWS expressed concerns about publically submitting individually ranked criteria. The group talked about preparing the RIC collectively as a TWG rather than submitting individual RIC’s from each agency. There was also a concern about whether the same Relative Importance Coefficient (RIC) should be used for all the sites. Some suggested that having a different RIC for each site would be more feasible since each site has different priorities. The TWG members were asked to email Bill with ideas about how the group should approach this step of the WRAM process in order to continue making progress with this task. The ideas and suggestions will be discussed among all of the TWG members in the coming weeks.

Action Items and Next Steps

- Provide suggestions to rank the criteria for the RIC portion of the Water Resources Assessment Methodology (WRAM). (All)
- Provide comments/suggestions on the gate conceptual drawings. (All)
- Make revisions to the gate conceptual drawings. (Khalid Ameri/Ben Geske)

The next TWG Meeting will be scheduled for the end of July, 2013.
OCAP Action IV.1.3

Technical Working Group Meeting Summary

Meeting Date/Time: 08/29/2013, 10:00am – 12:00pm

Location: DWR HQ in Room 210 and (Conference Call)

Participants

- Ben Geske, DWR
- Bill McLaughlin, DWR
- Colin Purdy, CDFW
- George Heise, CDFW
- Jacob McQuirk, DWR
- Jason Roberts, CDFW (phone)
- Jeff Stuart, NMFS
- Krystal Acierto, CDFW
- Subir Saha, DWR
- Ryan Reeves, DWR
- Kim Squires, BDFWO
Meeting Summary:

Bill McLaughlin started the meeting with introductions and then briefly explained the agenda and intent of the meeting. The group discussed how to best move forward with the WRAM process. A decision was made on how to come up with a relative importance coefficient for the entire group. A presentation was given by Ben Geske explaining the results from some modeling runs that included various physical gate operational scenarios.

Water Resources Assessment Method (WRAM) criteria ranking discussion

There was a discussion among the group regarding the WRAM criteria ranking. The goal for this meeting was to come up with an agreement on the best way to complete the relative importance criteria (RIC) portion of the WRAM. Many different suggestions were discussed. Three of the five agencies agreed that each agency should choose how they wanted to create their own set of RIC numbers. Bill McLaughlin will follow-up with USFWS and USBR (not in attendance during this conversation) to see if they agree with the idea as well. Each set of RIC numbers will remain anonymous, and will be averaged or blended to create one single set of RIC numbers that will represent the TWG group as a whole. The RIC numbers are to be completed within the next two weeks.

Presentation:

Physical Gate Modeling Results

Ben Geske gave a presentation that explained the results from various modeling scenarios. Bill explained some background as to why the modeling was requested, and what type of information that we were trying to gain through the modeling. Ben and Subir explained how the model was set up, and how the three scenarios differed from each other. The results were presented through graphs, open discussion, and questioning from meeting attendees. The group was asked to review the results and contact Ben with any follow-up questions, suggestions for improvement, and/or suggestions for additional modeling in the future.

Action Items and Next Steps

- Provide RIC numbers to Bill McLaughlin within two weeks in order to continue to make progress with the Water Resources Assessment Methodology (WRAM). (All)
- Provide comments/suggestions on additional modeling scenarios and what results folks would like to see from the modeling that has occurred. (All)

The next TWG Meeting will be scheduled for the middle of October, 2013.
OCAP Action IV.1.3

Technical Working Group Meeting Summary

Meeting Date/Time: 10/30/2013, 1:00am – 3:00pm

Location: DWR HQ in Room 335 and (Conference Call)

Participants

Ben Geske, DWR          Jeff Stuart, NMFS
Bill McLaughlin, DWR    Josh Brown, DWR
Colin Purdy, CDFW       Khalid Ameri, DWR
Jacob McQuirk, DWR      Ryan Reeves, DWR
Josh Israel, USBR (phone)
**Meeting Summary:**

Bill McLaughlin started the meeting with introductions and then briefly explained the agenda and intent of the meeting. The group was not able to discuss the Water Resources Assessment Methodology (WRAM) due to missing TWG members at the meeting. NMFS, DFW, and DWR have contributed a completed RIC document at this time. USFWS and Reclamation have yet to contribute their RIC documents. Ryan Reeves briefly talked about the upcoming 2014 Floating Fish Guidance Structure (FFGS) experiment at the Georgina Slough project site. A presentation was given by Ben Geske and Khalid Ameri explaining the FFGS conceptual designs at Georgiana Slough, Head of Old River, Turner Cut, and Columbia Cut.

**Presentation:**

**FFGS Conceptual Designs**

Ben and Khalid gave a presentation on the FFGS. They shared FFGS conceptual designs for Georgiana Slough, Head of Old River, Turner Cut, and Columbia Cut sites. Bill and Ryan gave some background as to why the FFGS has been considered as an engineering option. Ben and Khalid explained how the FFGS locations and alignments were determined at each individual site. It was concluded that the conceptual designs are based on the current available information and the design at Georgiana Slough might be altered after the 2014 FFGS Georgiana Slough study is completed. The Turner Cut and Columbia Cut conceptual designs will be altered once hydrodynamic data collected at those sites can be used to assist in locating the FFGS.

**Action Items and Next Steps**

- Follow up with USFWS and Reclamation to try and obtain their RICs. (Bill)
- Develop conceptual designs for other options. (Khalid Ameri/Ben Geske)
- Look into Marin Greenwood (ICF) presenting information on the Head of Old River synthesis report.

The next TWG meeting will be scheduled for the first or second week of December, 2013.
Meeting Date/Time: 12/10/2013, 1:00 pm – 3:00 pm

Location: DWR HQ in Room 210 and (Conference Call)

Participants

<table>
<thead>
<tr>
<th>Participant</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ben Geske, DWR</td>
<td></td>
</tr>
<tr>
<td>Bill McLaughlin, DWR</td>
<td></td>
</tr>
<tr>
<td>Bob Pedlar, DWR</td>
<td></td>
</tr>
<tr>
<td>Dave Huston, DWR (phone)</td>
<td></td>
</tr>
<tr>
<td>George Heise, CDFW</td>
<td></td>
</tr>
<tr>
<td>Jacob McQuirk, DWR</td>
<td></td>
</tr>
<tr>
<td>Steve Thomas, NMFS (phone)</td>
<td></td>
</tr>
<tr>
<td>Jeff Stuart, NMFS</td>
<td></td>
</tr>
<tr>
<td>Josh Brown, DWR</td>
<td></td>
</tr>
<tr>
<td>Khalid Ameri, DWR</td>
<td></td>
</tr>
<tr>
<td>Krystal Acierto, CDFW</td>
<td></td>
</tr>
<tr>
<td>Marin Greenwood, ICF</td>
<td></td>
</tr>
<tr>
<td>Ryan Reeves, DWR</td>
<td></td>
</tr>
</tbody>
</table>
Meeting Summary:

Bill McLaughlin started the meeting with introductions and then briefly explained the agenda and intent of the meeting. Bill briefly talked about the Water Resources Assessment Methodology (WRAM). It was mentioned that a follow up meeting with Reclamation is scheduled to obtain the only missing RIC numbers in order to go forward with the WRAM process. Ryan Reeves talked about the 2012 draft Georgiana Slough Non-Physical Barrier Report. He indicated that the 2012 report is ready to be reviewed by the group. He asked the group to provide their comments no later than January 13th.

A presentation was given by Marin Greenwood explaining juvenile salmonid routing, barrier effectiveness, predation, and predatory fishes at the Head of Old River. The second presentation was given by Ben Geske and Khalid Ameri explaining the Infrasound Fish Fence (IFF) conceptual designs at Georgiana Slough, Head of Old River, Turner Cut, and Columbia Cut.

Presentations:

Head of Old River Synthesis Report

Marin gave a presentation summarizing the synthesis report by describing studies and results that took place at the Head of Old River between 2009 and 2012. The studies were conducted to investigate two types of fish barriers. One was the BAFF and the other was the Rock Barrier. The studies were designed to investigate juvenile salmonid routing, predation on juvenile salmonids, barrier effects, and density changes in predatory fish. He shared some interesting results and recommendations with the group.

- 2010-2011 through-Delta survival results suggest the SJR route is no longer safer (SJRGA 2011, 2013)—survival is v. low by any route
- Although BAFF does deter fish, it gave only a modest improvement in protection efficiency
- BAFF effects undone by predation
- Rock barrier had greatest overall efficiency, but estimated predation was high (~40%)
- There is uncertainty in fate classification, but main conclusion (BAFF should not be used at this location) is robust

The draft report will be available to the group around the middle of January 2014.

IFF conceptual designs

Ben and Khalid gave a presentation on the IFF. Ben gave a brief background as to why the IFF has been considered as an engineering option because the technology was introduced to the group at a previous TWG meeting. Conceptual designs were shared for Georgiana Slough, Head of Old River, Turner Cut, and Columbia Cut sites. Ben and Khalid explained how the IFF locations and alignments were determined at each individual site. It was pointed out that this technology uses particle acceleration rather than sound pressure. Khalid mentioned that this technology
is not feasible to consider at the Head of Old River site due to the shallow water depth. He indicated that the zones of influence will be in contact with the channel bottom and water surface throughout the barrier alignment. As a result, this will lead to abnormal local environment effects at that site.

**Action Items and Next Steps**

- Follow up with Reclamation to obtain their RICs. (Bill)
- Compile and send additional IFF information with references to the group. (Ben)
- Review and provide comments on the 2012 Draft Georgian Slough Non-Physical Barrier Report by January 13th. (All)

The next TWG meeting will be scheduled for the last week of January or first week of February 2014.
Meeting Date/Time: 01/28/2014, 1:00 pm – 3:00 pm

Location: DWR HQ in Room 210 and (Conference Call)

**Participants**

Ben Geske, DWR

Bill McLaughlin, DWR

Bob Pedlar, DWR

Colin Purdy, CDFW

George Heise, CDFW

Jacob McQuirk, DWR

Jeff Stuart, NMFS

Khalid Ameri, DWR

Mark Holderman, DWR

Mike Cane, DWR

Ryan Reeves, DWR

Steve Thomas, NMFS (phone)
Meeting Summary:

Bill started the meeting with introductions and then briefly explained the agenda and intent of the meeting. Bill briefly gave an overview of the Franks Tract project on Threemile Slough. He mentioned that Reclamation staff was not able to attend the meeting and hopefully a presentation on the Franks Tract project will be given at the next TWG meeting.

A brief discussion was held regarding the 2012 draft Georgiana Slough Non-Physical Barrier Report comments. Colin indicated that he will send his comments to Bill this week. Jeff also indicated he will provide comments in the near future.

A presentation was given by DWR staff regarding design information for fish screens at Georgiana Slough, Head of Old River, Turner Cut, and Columbia Cut.

Presentations:

Fish Screen conceptual designs

Bill gave a background as to why fish screens have been considered as an engineering option. Ben shared design information for the Georgiana Slough, Head of Old River, Turner Cut, and Columbia Cut sites. The information included tabulated data showing how the design criteria inputs and outputs change according to the dynamic environment specific to each site. He also showed some preliminary calculations based on historical hydrodynamic data, channel geometry, and fish screening criteria. The objective of the presentation was to share BDO’s preliminary calculations with regards to NMFS and DFW’s fish screening criteria, and how they applied to each specific site. Concerns about failing to meet the criteria using site specific design flows and geometric layouts were also discussed.

Designing fish screens for the maximum diversion versus using average flows was discussed with the group. Maximum flows are extensively used in fish screen designs. The main concerns for designing fish screens at Georgian Slough and Head Old River were the size of the screens and being able to meet the approach velocity criteria of 0.2 fps (Delta Smelt) or 0.33 fps (Juvenile Salmonids) at all times. It was shown that in order to meet agencies design criteria, the size of the screens would be too large and not feasible to place in the junctions. However, for the Turner and Columbia Cut sites, the size of the screen was not a major concern. The main concerns for those two sites were the perpendicular flows and reverse flows which will cause fish to become impinged on the screen face and approach velocities not being met at all times. It was indicated that reverse flows occur about 50% of the time at Turner Cut and Columbia Cut which further complicates operation of a fish screen.

A discussion was had regarding the possibility for using partial column screens instead of full column screens. George indicated that this type of technology would still need to adhere to the current fish screening criteria, and that it seems to have similar issues to the full screen option. It was suggested to look into other technologies that
might be more feasible than the fish screen such as the Floating Fish Guidance Structure that will be field tested this spring at Georgiana Slough.

In summary, the TWG members present (NMFS, DFW, and DWR) were agreeable to dropping a fish screen as an option. However, fish screening technologies may be combined with other engineering options in order to maximize fish deterrence if appropriate. USFWS and Reclamation staff not present at the meeting will be briefed on the meeting and asked if they formally concur with the other TWG members to drop the fish screen option.

**Action Items and Next Steps**

- Follow up with Reclamation and USFWS to obtain feedback and concurrence on dropping the fish screen technology from further consideration. (Bill)
- Coordinate with Reclamation to give a presentation on the Franks Tract project at the junction of the Sacramento River and Threemile Slough. (Bill)
- Develop conceptual designs for the Threemile Slough site. (Khalid/Ben)
- Provide comments on the 2012 Draft Georgiana Slough Non-Physical Barrier Report. (All)

The next TWG meeting will be scheduled for the second week of March 2014.
Meeting Date/Time: 04/30/2014, 10:30 am – 12:30 pm

Location: DWR HQ in Room 210

Participants

Ben Geske, DWR
Bill McLaughlin, DWR
Dave Huston, DWR (phone)
George Heise, CDFW
Jacob McQuirk, DWR
Jeff Stuart, NMFS (phone)
Josh Israel, USBR (phone)
Khalid Ameri, DWR
Mike Cane, DWR
Roy Leidy, AECOM
Ryan Reeves, DWR
Meeting Summary:

Bill opened the meeting by introducing the participants both on the phone and in the room. He described the agenda for the meeting and then started the presentation of the engineering solutions design packet.

A presentation was given by Ben and Khalid showing the latest set of conceptual designs for Georgiana Slough, Threemile Slough, Head of Old River, Turner Cut, and Columbia Cut. Ben and Khalid went through each drawing, for each individual site, and explained changes that were made due to new information or comments from previous TWG meetings. Questions and comments about the design, and how it addresses the ranking criteria, were encouraged by staff. Ryan suggested that we extend the upstream end of the Georgiana Slough FFGS further upstream, and closer to the river’s edge. This could possibly improve deterrence by minimizing the number of fish going behind the barrier.

Josh discussed how additional water along with an engineering option for deterrence would be beneficial to the downstream migrants. The gate designs could accomplish this but to the detriment of the interior Delta based on modeling runs made on the impacts of decreased flows in Georgiana Slough, Head of Old River, Turner Cut, and Columbia Cut.

Bill asked the group to review the conceptual design package and provide comments. He concluded that the changes to the designs will be incorporated once all comments/suggestions are received from the group. Bill indicated that this process will help us with ranking each engineering option during the next step in the WRAM process.

Action Items and Next Steps

- Provide comments on the engineering options conceptual design package. (All)
- Make changes to drawings due to comments and suggestions from this meeting. (Geske/Ameri)
- Start working on the final report write-ups. (DWR)

The next TWG meeting will be scheduled for mid-June 2014.
Meeting Date/Time: 06/17/2014, 1:00 pm – 3:00 pm

Location: DWR HQ in Room 210

**Participants**

Ben Geske, DWR

Bill McLaughlin, DWR

Bob Pedlar, DWR

George Heise, CDFW

Jacob McQuirk, DWR

Jeff Stuart, NMFS (phone)

Khalid Ameri, DWR

Michael Eakin, CDFW

Roy Leidy, AECOM
**Meeting Summary:**

Bill opened the meeting with introductions and described the agenda for the meeting. He then discussed the write-ups that support the conceptual designs and their significance during the OCC portion of the WRAM evaluation. The group discussed how to best move forward with the 2nd phase of the WRAM process which is to evaluate different engineering options at the individual sites. The draft Georgiana Slough FFGS write-up was discussed. Bill mentioned that staff is in the process of producing write-ups for all four options at each of the five sites (20 total write-ups).

The group discussed how to evaluate the predation effects for each option when there is no baseline densities of predators that exist at any of the junctions. Bill indicated that it would be difficult to determine whether a specific engineering option would contribute to predation rates of Juvenile salmonids in the absence of a baseline study. Roy Leidy pointed out that AECOM is currently working on the Synthesis report to examine the BAFF and Rock Barrier at the Head of Old River for predation impacts. This would be accomplished by investigating the predator density, predator behavior, and predation rates that occurred in the vicinity of the HOR during the studies.

There was a discussion about the deterrence effectiveness of the options that are currently on the table. Infrasound is one of the options which we are currently considering, but has not been tested in an environment such as the Sacramento River or San Joaquin River. Michael Eakin inquired about the possibility of the IFF units harming Delta Smelt larva due to the intense vibrations close to the units. Ben answered by saying that the IFF manufacturer (Profish - Sonny Damien) does not believe that the vibrations would harm very small fish, but also said that there hasn’t been any tests to prove that yet. Jacob followed up with the idea that we (TWG group) would suggest that there be further laboratory and field testing conducted prior to permanent installation to answer the question. George and Roy both mentioned that it was important for all of the TWG members to have a consistent definition for all of the criteria while evaluating the options. A document containing the criteria definitions and “questions to ask yourself” during the grading process was sent to all the TWG members to review it in order keep the TWG members on the same thought process through this evaluation.

The Group discussed in general the difficulty in comparing options based on limited studies not reflecting variable conditions (i.e., flow) and in many cases no studies. (e.g., flow conditions during the Georgiana Slough BAFF tests varied but only low flow conditions occurred during the 2014 FFGS study. Jeff mentioned that he recalls a temporal flow period greater than 25,000 cfs. George suggested that we focus on dry and average water year types while evaluating the options. This was agreed upon by all meeting attendees. This should capture the periods when fish protection is most necessary.
The Group discussed potential sediment accumulation issues associated with options at some sites, primarily the Head of Old River shallower water depths. These potential issues should be considered and how they may affect O&M and performance.

Jacob mentioned that tidal excursion changes resulting from proposed plans to open up Liberty Island to tidal flows and other BDCP actions may influence the option evaluations. These potential changes should be considered. This is just one of many elements of the BDCP project that may influence option evaluations.

Bill asked the group to review the Georgiana slough FFGS draft write-up and provide comments. He concluded that the final write-up format will be used as a basis to provide consistent information to the group for all option write-ups.

**Action Items and Next Steps**

- Provide comments on the Georgiana Slough FFGS write-up. (All)
- Send out the final RIC values. (McLaughlin)
- Start working on the other engineering options write-ups. (Geske/Ameri)
- Post Georgiana Slough and HOR BAFF study reports on DWR Portal (McLaughlin)

The next TWG meeting will be scheduled for end of July or beginning of August 2014.
Meeting Date/Time: 08/06/2014, 1:00 pm – 3:00 pm

Location: DWR HQ in Room 210

Participants

Ben Geske, DWR

Bill McLaughlin, DWR

Bob Pedlar, DWR

George Heise, CDFW

Jacob McQuirk, DWR

Jeff Stuart, NMFS (phone)

Khalid Ameri, DWR

Michael Eakin, CDFW

Roy Leidy, AECOM

Steve Thomas, NMFS (phone)
Meeting Summary:

Bill opened the meeting with introductions and described the agenda for the meeting. He briefly discussed the conceptual design write-ups that support the OCC portion of the WRAM evaluation. Bill mentioned that staff is in the process of producing additional write-ups for the group to review. He asked the group to review the draft write-ups and provide comments. Jeff suggested addressing potential issues with boat navigation during extreme dry (drought) and high water conditions in the write-ups, especially for the BAFF at the Head of Old Rive option.

An Excel spreadsheet containing the OCC portion of the WRAM evaluation was discussed to keep the TWG members on the same thought process through this evaluation. Bill shared the combined averaged RIC values with the group. Bill added that he will send out the spreadsheet to the group for ranking around the end of August.

A draft outline for the Phase II report was discussed among the TWG members. Bill asked the group to review the outline and provide comments no later than August 14th. Bill indicated that the First Draft of the Phase II report would be completed by October 1st and the TWG members would potentiality have a month to review and provide comments.

Action Items and Next Steps

- Provide comments on the conceptual design write-ups. (All)
- Provide comments on the Final Draft Report Outline no later than August 14th. (All)
- Send out the OCC portion of the WRAM evaluation Excel sheet to the TWG members. (McLaughlin)
- Continue work on the engineering options write-ups. (Geske/Ameri)
The next TWG meeting will be scheduled for the middle of September 2014.
Meeting Date/Time: 12/16/2014, 10:00 am – 12:00 pm

Location: DWR HQ in Room 210

Participants

Ben Geske, DWR
Bill McLaughlin, DWR
Bob Pedlar, DWR
George Heise, CDFW
Jacob McQuirk, DWR
Jeff Stuart, NMFS (phone)
Khalid Ameri, DWR
Michael Eakin, CDFW
Roy Leidy, AECOM
Ryan Reeves, DWR
**Meeting Summary:**

Bill described the agenda for the meeting. The draft Phase II report was discussed. Bill asked the group to review the report and provide comments no later than January 12\textsuperscript{th}, 2015. Bill stated that as planned the draft does not include completed chapters 5 (WRAM Assessments) or 6 (Recommendations). Bill indicated that a revised Phase II draft report would then be distributed to the TWG members on February 9, 2015 with comments due no later than February 23, 2015. He discussed the costs associated with the conceptual designs. He indicated that he will send updated cost information which will include O&M and present worth costs for each option within a week.

Bill requested the TWG members provide recommendations to be included in the report. The current draft does not include recommendations (Chapter 6). It would be helpful to have TWG members provide input. Potential recommendations include: reviewing the 2014 FFGS report once it is finalized (data processing on-going), review other in-progress studies (6-year study, ELAM modeling, etc….), additional evaluations of technologies, and additional modeling (junction and operations). Re-assessing the options should also be considered as additional information is obtained.

Bill also discussed the OCC portion of the WRAM evaluation. An Excel spreadsheet containing the OCC portion of the WRAM evaluation was presented along with directions for completing it. Bill added that each agency would come up with one set of OCC numbers. Bill also suggested that as was done for the RIC numbers, averaging the OCC numbers from the five agencies seems to be the best strategy versus trying to have a consensus among everyone. Bill will follow-up with USFWS and USBR to let them know about the OCC process since they were not in attendance during this meeting. Bill indicated that the due date to submit the OCC numbers is also January 12\textsuperscript{th}.

**Action Items and Next Steps**

- Provide comments on the Phase II draft report no later than January 12\textsuperscript{th}, 2015. (All)
- Provide recommendations to be included in Chapter 6 no later than January 12\textsuperscript{th}, 2015. (All)
• Provide OCC numbers for the WRAM evaluation no later than January 12th, 2015. (All)

• Provide updated cost information for the conceptual designs to the TWG members within a week. (McLaughlin)
CONCEPTUAL ENGINEERING DRAWINGS FOR
GEORGIANA SLOUGH
NMFS BiOp RPA ACTION IV.1.3
SACRAMENTO COUNTY, CALIFORNIA

INDEX OF SHEETS
Sheet 1 of 19 – Title Sheet and Area Map
Sheet 2 of 19 – BAFF: Plan
Sheet 3 of 19 – BAFF: Elevation
Sheet 4 of 19 – BAFF: Detail
Sheet 5 of 19 – IFF: Plan
Sheet 6 of 19 – IFF: Elevation
Sheet 7 of 19 – IFF: Detail
Sheet 8 of 19 – FFGS: Plan
Sheet 9 of 19 – FFGS: Elevation
Sheet 10 of 19 – FFGS: Detail
Sheet 11 of 19 – Gate: Site Plan
Sheet 12 of 19 – Gate: Plan
Sheet 13 of 19 – Gate: Elevation
Sheet 14 of 19 – Gate: Section
Sheet 15 of 19 – Gate: Boat Lock
Sheet 16 of 19 – Gate: Vertical Slot Fish Ladder
Sheet 17 of 19 – Gate: Fish Ladder Detail
Sheet 18 of 19 – Gate: Overflow Gate Detail
Sheet 19 of 19 – Gate: Underflow Gate Detail

PRELIMINARY
SUBJECT TO REVISION
Elevation: Infrasound Fish Fence
Location: Georgiana Slough

Date Drawn: 07–14–2014
Drawn By: Ben Geske

State of California
Natural Resources Agency
Department of Water Resources
Bay–Delta Office

[Diagram showing elevation measurements along a fish fence, with different elevation levels labeled: High WSE 13.5', Avg WSE 5.5', Low WSE 1.1', and Channel Bottom.]
Red = Zone of exclusion from structural entities.
Blue = Fish deterrence zone.
Green = Boundary for measurable particle acceleration.
Gates with Boat Lock & Fish Ladder - Georgiana Slough

Top of Structure 17.5' NAVD88

Boat Lock Gate & 6 Bottom Hinged Gates

Vertical Slot Fish Ladder

Existing Elevation (River Thalweg)

High WSE 13.5' NAVD88

Avg WSE 5.5' NAVD88

Low WSE 1.1' NAVD88

SECTION B - B
20 Bay Vertical Slot Fish Ladder for Georgiana Slough
Detail: Underflow Gate
Location: Georgiana Slough
CONCEPTUAL ENGINEERING DRAWINGS FOR
THREEMILE SLOUGH
NMFS BiOp RPA ACTION IV.1.3

SACRAMENTO COUNTY, CALIFORNIA

INDEX OF SHEETS

<table>
<thead>
<tr>
<th>Sheet</th>
<th>of 18</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Title Sheet and Area Map</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>BAFF: Plan</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>BAFF: Elevation North</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>BAFF: Elevation South</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>BAFF: Detail</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>IFF: Plan</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>IFF: Elevation North</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>IFF: Elevation South</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>IFF: Detail</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>FFGS: Plan</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>FFGS: Elevation North</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>FFGS: Elevation South</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>FFGS: Detail</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>Gate: Plan</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>Gate: Plan &amp; Section</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>Gate: Boat Lock Plan</td>
</tr>
<tr>
<td>17</td>
<td>1</td>
<td>Gate: Boat Lock Section</td>
</tr>
<tr>
<td>18</td>
<td>1</td>
<td>Gate: Detail</td>
</tr>
</tbody>
</table>

PRELIMINARY
SUBJECT TO REVISION

Date Drawn: 10-7-2014
Drawn By: Ben Geske
Khalid Ameri

Title Sheet and Area Map
Location: Threemile Slough

State of California
Natural Resources Agency
Department of Water Resources
Bay-Delta Office
Red = Zone of exclusion from structural entities.
Blue = Fish deterrent zone.
Green = Boundary for measurable particle acceleration.
Plan: Floating Fish Guidance Structure
Location: Threemile Slough
Detail: Floating Fish Guidance Structure
Location: Threemile Slough

Date Drawn: 06-24-2014
Drawn By: Ben Geske
Plan: Boat Lock
Location: Threemile Slough

NOTES
1. ACCESS LADDERS NOT SHOWN FOR CLARITY.
Section: Boat Lock
Location: Three Mile Slough
CONCEPTUAL ENGINEERING DRAWINGS FOR
HEAD OF OLD RIVER
NMFS BiOp RPA ACTION IV.1.3
SAN JOAQUIN COUNTY, CALIFORNIA

INDEX OF SHEETS

Sheet 1 of 18 – Title Sheet and Area Map
Sheet 2 of 18 – BAFF: Plan
Sheet 3 of 18 – BAFF: Elevation
Sheet 4 of 18 – BAFF: Detail
Sheet 5 of 18 – FFGS: Plan
Sheet 6 of 18 – FFGS: Elevation
Sheet 7 of 18 – FFGS: Detail
Sheet 8 of 18 – Gate: Site Plan
Sheet 9 of 18 – Gate: Plan
Sheet 10 of 18 – Gate: Elevation
Sheet 11 of 18 – Gate: Section
Sheet 12 of 18 – Gate: Boat Lock
Sheet 13 of 18 – Gate: Vertical Slot Fish Ladder
Sheet 14 of 18 – Gate: Fish Ladder Detail
Sheet 15 of 18 – Gate: Overflow Gate Detail
Sheet 16 of 18 – Gate: Underflow Gate Detail
Sheet 17 of 18 – SDIP – Gate Plan
Sheet 18 of 18 – SDIP – Gate Elevation

PRELIMINARY SUBJECT TO REVISION
High WSE 17.1'
Avg. WSE 3.8'
Low WSE 0'
Existing Ground
Plan: Gates with Boat Lock & Fish Ladder
Location: Head of Old River
Underflow or Overflow Gates
Boat Lock
Vertical Slot
Fish Ladder
Trash Rack
PLAN

SECTION B-B

Detail: Vertical Slot Fish Ladder
Location: Head of Old River
Detail: Vertical Slot Fish Ladder
Location: Head of Old River

Flow
Stop Log
Detail: Vertical Slot Fish Ladder
Location: Head of Old River
Detail: Radial Arm Gate
Location: Head of Old River
Plan: SDIP – Old River Fish Control Structure
Location: Head of Old River

NOTES
1. Maintain adequate construction access to the existing temporary rock barrier and lagoon spills.
2. Denotes Gate number
3. Denotes Pile number
STRUCTURE PROFILE
Scale: 1"=20'

NOTES
1. Vertical Datum - 1988 NAVD
2. Sheet pile not shown for clarity.
CONCEPTUAL ENGINEERING DRAWINGS FOR

TURNER CUT
NMFS BiOp RPA ACTION IV.1.3

SAN JOAQUIN COUNTY, CALIFORNIA

INDEX OF SHEETS

Sheet 1 of 20 – Title Sheet and Area Map
Sheet 2 of 20 – BAFF: Plan
Sheet 3 of 20 – BAFF: Elevation East
Sheet 4 of 20 – BAFF: Elevation West
Sheet 5 of 20 – BAFF: Detail
Sheet 6 of 20 – IFF: Plan
Sheet 7 of 20 – IFF: Elevation
Sheet 8 of 20 – IFF: Detail
Sheet 9 of 20 – FFCS: Plan
Sheet 10 of 20 – FFCS: Elevation
Sheet 11 of 20 – FFCS: Detail
Sheet 12 of 20 – Gate: Site Plan
Sheet 13 of 20 – Gate: Plan
Sheet 14 of 20 – Gate: Elevation
Sheet 15 of 20 – Gate: Section
Sheet 16 of 20 – Gate: Boat Lock
Sheet 17 of 20 – Gate: Vertical Slot Fish Ladder
Sheet 18 of 20 – Gate: Fish Ladder Detail
Sheet 19 of 20 – Gate: Overflow Gate Detail
Sheet 20 of 20 – Gate: Underflow Gate Detail

PRELIMINARY SUBJECT TO REVISION
Detail: Bio-Acoustic Fish Fence

Location: Turner Cut

Date Drawn: 08-12-2010

Drawn By: EIMCO
Red = Zone of exclusion from structural entities.
Blue = Fish dterrence zone.
Green = Boundary for measurable particle acceleration.
Boat Lock Gate
Top of Structure 16.2' NAVD88
4 Radial Arm Gates
Vertical Slot
Fish Ladder
High WSE 12.2' NAVD88
Avg. WSE 8.8' NAVD88
Low WSE -1.0 NAVD88
Detail: Bio-Acoustic Fish Fence
Location: Columbia Cut
Red = Zone of exclusion from structural entities.
Blue = Fish ditherence zone.
Green = Boundary for measurable particle acceleration.
Bottom Hinged Gates with Boat Lock & Fish Ladder - Columbia Cut

- Vertical Slot Fish Ladder with Trash Rack
- Boat Lock
- 5 Bottom Hinged Gates (38' Height)
- 11 Bottom Hinged Gates (24' Height)

Abutment

232.6'

20' (TYP)

338'

Plan: Gate, Boat Lock, and Fish Ladder
Location: Columbia Cut
Gates with Boat Lock & Fish Ladder @ Columbia Cut

ELEVATION A - A
Looking Downstream
Gates with Boat Lock & Fish Ladder @ Columbia Cut

11 Bottom Hinged Gates (24' Height)
5 Bottom Hinged Gates (38' Height)

Top of Structure 12.2' NAVD88

Boat Lock Gate
Vertical Slot Fish Ladder

Boat Lock Gate

High WSE 12.2' NAVD88
Avg WSE 8.8' NAVD88
Low WSE -1.0' NAVD88

Right Channel (EG)
Left Channel (EG)

SECTION B - B
20 Bay Vertical Slot Fish Ladder for Columbia Cut

Flow

Avg WSE 8.8' NAVD88

Existing Elevation (River Thalweg)

S = 10%
Memorandum

To: Bill McLaughlin, Senior Engineer, California Department of Water Resources
From: Jennifer Aranda, Senior Project Manager, AECOM
Date: August 22, 2014
Subject: Preliminary Environmental Evaluation of the Georgiana Slough Study Site

AECOM technical staff conducted a preliminary evaluation of the Georgiana Slough study site under consideration for engineering solutions to reduce diversion of emigrating juvenile salmonids to the interior and southern portions of the Sacramento–San Joaquin Delta (Delta), and to reduce salmonid exposure to Central Valley Project and State Water Project export facilities.

METHODS

A preliminary list of potential environmental issues associated with the Georgiana Slough study site is presented in Table 1. AECOM evaluated the study site within the boundary that was provided by the California Department of Water Resources (DWR) (Figure 1); site access, staging areas, and materials stockpile areas were not identified outside the site boundary, and therefore were not assessed for potential environmental issues. Potentially significant environmental issues have been identified that would require further evaluation before beginning final design because they may influence project design, timing, and project construction options. In addition, informal consultation with the National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), U.S. Army Corps of Engineers (USACE), Central Valley Regional Water Quality Control Board (RWQCB), and California Department of Fish and Wildlife (CDFW) should occur before final project design. This informal consultation would help identify the in-channel construction period and would help develop mitigation and avoidance measures to minimize short-term construction-related impacts on species protected under the federal Endangered Species Act (ESA) and California Endangered Species Act (CESA).

BIological resources

The sensitive species included in Table 2 are known to occur in the study site vicinity, and suitable habitat for the species may present within the study site, based on a review of aerial photography and limited site access. Special-status fish species are known to occur within the study site and have the potential to be directly affected by project implementation. Furthermore, field surveys would be required for special-status plants, and the surveys should be timed to coincide with the blooming period (see notes in Table 2) of target species. One occurrence of Sanford’s arrowhead is documented along the banks of Georgiana Slough. The preliminary site evaluation suggests that the trees along the waterways provide suitable nest locations for Swainson’s hawk and white-tailed kite. Avoidance and minimization measures should be developed for all special-status species that have the potential to occur within the study site, as well as including these measures as “environmental commitments” as part of the project description or as mitigation measures for any potentially significant impacts.
Figure 1. Location Map
CULTURAL RESOURCES

A record search of pertinent cultural resources information was conducted, curated at the California Historical Resources Information System at the North Central Information Center (NCIC). According to NCIC, the southwest portion of the study site has been inventoried (NCIC report #4171). Two cultural resources have been identified within the study site: CA-SAC-329 and P-34-4297.

CA-SAC-329 is a prehistoric cultural midden site with human remains. Although this site was partially excavated in 1975, it has not been formally evaluated for National Register of Historic Places (NRHP) and California Register of Historic Resources (CRHR) significance. However, sites containing human remains are treated as eligible for inclusion in the NRHP and CRHR. DWR would need to implement avoidance measures, to avoid directs impacts on this unique resource that also possess sacred Native American values.

P-34-4297 is Bridge #24C0005, constructed in 1950. This bridge has been formally evaluated and has been determined not to be eligible for inclusion in the NRHP and CRHR.

In addition to the NCIC record search, the California State Lands Commission Shipwreck Database was consulted, and no cultural resources were identified within the study site. Bridge #24C0005 is within the study site boundary but previously was determined not eligible for the NRHP and the CRHR. Commercial buildings more than 50 years old are within the study site, and they would need to be evaluated for NRHP and CRHR significance. Portions of the levees within the study site also are more than 50 years old, and they also would need to be evaluated for NRHP and CRHR significance.

PERMITS AND AUTHORIZATIONS

Work at the Georgiana Slough study site may require permits or authorizations from federal, state, and regional and local agencies with regulatory jurisdiction over the environmental resources that are present (Table 3). USACE 408 permission would be required if the project would affect the levees in the study site, all of which are USACE project levees. DWR may need a permit (Nationwide or Individual) from USACE under Section 404 of the Clean Water Act (CWA), if project implementation requires placement of dredge and fill materials into waters of the United States. An Individual Permit and CWA Section 404(b)(1) alternatives analysis are required if permanent wetland impacts exceed the 0.5 acre threshold of the Nationwide Permit program. Impacts on waters of the United States may require implementation of mitigation measures. Compliance with Section 106 of the National Historic Preservation Act would be required to obtain a Section 404 permit. Placement of structures in navigable waterways would require authorization from USACE under Section 10 of the Rivers and Harbors Act of 1899.

The 404 permit would provide the federal nexus for an ESA Section 7 consultation. Formal ESA consultation requires up to 135 days for agency review after project design, timing, and avoidance and mitigation measures have been identified. However, USFWS has recently acknowledged achieving the 135-day consultation timeline may no longer be possible for all projects, especially for projects without multi-benefits. As a result, USFWS is prioritizing workload and not all projects will conclude formal ESA consultation within 135 days. High-level discussion with USFWS will be needed to expedite ESA compliance. Consultation with NMFS would also be required because of potential impacts to anadromous fish. A Rivers and Harbors Act Section 9 Permit may be required from the U.S. Coast Guard. Compliance with the National Environmental Policy Act (NEPA) would be required if any federal funding is used by the project.

Water quality certification from the Central Valley RWQCB would be required for compliance with Section 401 of the CWA. This certification would identify project-specific best management practices (BMPs) to minimize project impacts, such as criteria to reduce erosion, sedimentation, and releases of hazardous material. BMPs also would provide criteria for dewatering and construction methods, revegetation, and
monitoring requirements. A National Pollutant Discharge Elimination System (NPDES) Construction General Permit for discharges of stormwater associated with the construction activity would be required if total soil disturbance exceeds 1 acre. Soil disturbance typically occurs from access improvements, staging areas, material stockpile areas, and construction areas.

A Lake and Streambed Alteration Agreement (LSAA) would be required from CDFW under Section 1600 et seq. of the California Fish and Game Code, to address potential project-related impacts on the bed, banks, and channel of any natural stream and associated riparian vegetation. Both water quality certification and the LSAA would require evidence of compliance with the California Environmental Quality Act (CEQA) before issuance of permits.

Species protected under CESA could occur within the study site or in the study site vicinity. If the potential exists for the project to result in “take” (i.e., kill) of a special-status species that is protected under CESA, an incidental take permit would be required from CDFW. Typically, avoidance and minimization measures can be implemented before project construction to avoid the direct mortality of species protected under CESA.

Encroachment permits may need to be obtained from the Central Valley Flood Protection Board and Reclamation District No. 0003, No. 0554, and No. 0556. DWR has a Memorandum of Understanding with the California State Lands Commission (CSLC), which became effective on October 19, 1979. DWR is authorized to perform certain types of activities without obtaining a lease from CSLC. The project would need to be evaluated further for compliance with the lease after detailed, project-specific information is available.

The project may require a consistency determination from the Delta Stewardship Council, if the project achieves the criteria of a “covered action” and “will have a significant [positive or negative] impact on the achievement of one or both of the coequal goals or the implementation of government-sponsored flood control programs to reduce risks to people, property, and state interests in the Delta.” The coequal goals are: (1) providing a more reliable water supply for California; and (2) protecting, restoring, and enhancing the Delta ecosystem.

A Sacramento County grading permit may be required, if clearing and grubbing exceeds 1 acre or fill exceeds 350 cubic yards of material. A Sacramento County tree permit may be required, if tree removal or trimming of any tree located on public premises is proposed.

If you have any questions about the information provided or need additional information, please contact me at (916) 414-5858, or by e-mail (jennifer.aranda@aecom.com).
### Table 1  Potential Environmental Issues Associated with the Georgiana Slough Study Site

<table>
<thead>
<tr>
<th>Environmental Issue Area</th>
<th>Preliminary Evaluation Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aesthetics</td>
<td>Potential short-term impacts on State Route 160, officially designated as a State and County Scenic Highway, may require a Caltrans encroachment permit. DWR would need to coordinate with the U.S. Coast Guard on the positioning of any in-water lights, navigational buoys, and signage; and would have to remove all equipment, lights, buoys, and signage at the end of the project.</td>
</tr>
<tr>
<td>Agriculture and Forestry Resources</td>
<td>Temporary construction-related impacts may occur if agricultural lands are used for staging or materials storage. There are no forestry resources on site.</td>
</tr>
<tr>
<td>Air Quality</td>
<td>Short-term impacts from construction emissions (from construction equipment and vehicles, or fugitive dust) may require measures to minimize emissions.</td>
</tr>
<tr>
<td>Biological Resources</td>
<td>Potentially significant ESA and CESA take issues related to construction activities, including in-channel work and dewatering activities, may occur.</td>
</tr>
<tr>
<td>Cultural Resources</td>
<td>An NRHP-eligible/CCHR significant prehistoric site is within the study site. The project design should avoid direct impacts on this resource. Assessment of the NRHP/CCHR significance of the commercial buildings and levees would be required. Potential impacts on built environment cultural resources are unlikely to occur; however, DWR would be required to conduct an inventory and evaluation by a cultural resources specialist for permitting. The study site is not considered to be paleontologically sensitive, and therefore no impacts to this resource would occur.</td>
</tr>
<tr>
<td>Environmental Justice</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Geology and Soils</td>
<td>Short-term construction-related erosion could result in sediment transport from land into Georgiana Slough, and short-term water-based construction could increase turbidity in the channel. Mitigation measures will be required to prevent erosion and decrease turbidity. Construction in unstable soils, subsidence, and liquefaction could represent hazards; however, these issues could be addressed during the engineering phase of project design.</td>
</tr>
<tr>
<td>Greenhouse Gas Emissions</td>
<td>Short-term construction-related greenhouse gas emissions may occur, but they are not likely to exceed the greenhouse gas thresholds developed by DWR.</td>
</tr>
<tr>
<td>Hazards and Hazardous Materials</td>
<td>A potential risk exists for release of hazardous materials (e.g., cement, fuel, or lubricants) associated with the project. DWR should design the project to minimize risk. DWR may be required to implement a hazardous materials management program. Walnut Grove Elementary School is located approximately 0.2 mile east of the study site.</td>
</tr>
<tr>
<td>Hydrology and Water Quality</td>
<td>Potential short-term impacts on water quality may occur during project construction and operation. Potential changes to water turbidity, stage, and velocity also may occur during project construction and operation. DWR will need to implement avoidance and mitigation measures to protect water quality and monitor turbidity.</td>
</tr>
<tr>
<td>Land Use and Planning</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Mineral Resources</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Noise</td>
<td>Short-term construction-related impacts may occur. DWR should limit construction to daytime hours and should employ noise-reducing construction practices.</td>
</tr>
<tr>
<td>Population and Housing</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Public Health and Safety</td>
<td>Construction activities may temporarily affect public health from the potential release of hazardous materials associated with the project. DWR may be required to implement a hazardous materials management program.</td>
</tr>
<tr>
<td>Public Services</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Recreation</td>
<td>Potential impacts may occur on marinas, boating, and related recreational activities within the study site, particularly during daytime in summer. The project design should maintain navigation and DWR should coordinate with the U.S. Coast Guard on the positioning of any in-water lights, navigational buoys, and signage.</td>
</tr>
<tr>
<td>Transportation and Traffic</td>
<td>Potential short-term impacts may occur on bridges in the study site, requiring a U.S. Coast Guard Section 9 permit, and work in the vicinity of State Route 160 may require a Caltrans encroachment permit. The project design should maintain navigation and DWR should coordinate with the U.S. Coast Guard on the positioning of any in-water lights, navigational buoys, and signage.</td>
</tr>
<tr>
<td>Utilities and Service Systems</td>
<td>No issues or impacts have been identified.</td>
</tr>
</tbody>
</table>

Notes: CESA = California Endangered Species Act; CRHR = California Register of Historical Resources; DWR = California Department of Water Resources; ESA = Endangered Species Act; NRHP = National Register of Historic Places
Table 2  Potentially Occurring State and Federally Listed Species in the Georgiana Slough Study Site Vicinity

<table>
<thead>
<tr>
<th>Class</th>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plants</td>
<td><em>Hibiscus lasiocarpos</em> var. <em>occidentalis</em></td>
<td>Wooly rose mallow</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td></td>
<td><em>Lathyrus jepsonii</em> var. <em>jepsonii</em></td>
<td>Delta tule pea</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td></td>
<td><em>Lilaeopsis masonii</em></td>
<td>Mason's lilaeopsis</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td></td>
<td><em>Limosella australis</em></td>
<td>Delta mudwort</td>
<td>CRPR 2</td>
</tr>
<tr>
<td></td>
<td><em>Sagittaria sanfordii</em></td>
<td>Sanford's arrowhead</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td></td>
<td><em>Symphyotrichum lentum</em></td>
<td>Suisun marsh aster</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td>Invertebrates</td>
<td><em>Desmocerus californicus dimorphus</em></td>
<td>Valley elderberry longhorn beetle</td>
<td>FT</td>
</tr>
<tr>
<td>Fish</td>
<td><em>Acipenser medirostris</em></td>
<td>Green sturgeon (southern DPS)</td>
<td>FT</td>
</tr>
<tr>
<td></td>
<td><em>Hypomesus transpacificus</em></td>
<td>Delta smelt</td>
<td>FT, FX, CE</td>
</tr>
<tr>
<td></td>
<td><em>Oncorhynchus tshawytscha</em></td>
<td>Sacramento River winter-run Chinook salmon</td>
<td>FE, FX, CE</td>
</tr>
<tr>
<td></td>
<td><em>Oncorhynchus tshawytscha</em></td>
<td>Central Valley spring-run Chinook salmon</td>
<td>FT, FX, CT</td>
</tr>
<tr>
<td></td>
<td><em>Oncorhynchus mykiss</em></td>
<td>Central Valley steelhead DPS</td>
<td>FT, FX, CT</td>
</tr>
<tr>
<td></td>
<td><em>Pogonichthys macrolepidotus</em></td>
<td>Sacramento splitfin</td>
<td>SSC</td>
</tr>
<tr>
<td></td>
<td><em>Spirinchus thaleichthys</em></td>
<td>Longfin smelt</td>
<td>FC, CT, SSC</td>
</tr>
<tr>
<td>Amphibians</td>
<td><em>Emys marmorata</em></td>
<td>Western pond turtle</td>
<td>SSC</td>
</tr>
<tr>
<td>Birds</td>
<td><em>Buteo swainsoni</em></td>
<td>Swainson’s hawk</td>
<td>CT</td>
</tr>
<tr>
<td></td>
<td><em>Elanus lecurus</em></td>
<td>White-tailed kite</td>
<td>FP</td>
</tr>
<tr>
<td>Mammals</td>
<td><em>Lasiurus blossevillii</em></td>
<td>Western red bat</td>
<td>SSC</td>
</tr>
</tbody>
</table>

Notes: DPS = distinct population segment
1 Known to occur within the study site; 2 Blooming Period: June-September; 3 Blooming Period: May-September; 4 Blooming Period: April-November;
5 Blooming Period: May-August; 6 Blooming Period: May-November

Status Notes:

**U.S. Fish and Wildlife Service (USFWS):**

FT = Listed as threatened under the federal Endangered Species Act
FC = Candidate for listing under the federal Endangered Species Act
FX = Critical Habitat

**California Department of Fish and Wildlife (CDFW):**

CE = Endangered (legally protected)
FP = Fully protected species—may not be taken or possessed without a permit from the Fish and Game Commission
SSC = California Species of Special Concern
CT = Threatened (legally protected)

**California Native Plant Society:**

CRPR 1B = Plant species considered rare or endangered in California and elsewhere (protected under the California Environmental Quality Act, but not legally protected under the Endangered Species Act or California Endangered Species Act)
CRPR 2 = Plant species considered rare or endangered in California but more common elsewhere (protected under the California Environmental Quality Act, but not legally protected under the Endangered Species Act or California Endangered Species Act)

Search Criteria: Database searches were conducted using the USFWS online database, CDFW's California Natural Diversity Database (CNDDB), and California Native Plant Society's (CNPS) Inventory of Rare and Endangered Plants of California to identify sensitive species that could occur in the study site. The database searches included the U.S. Geological Survey (USGS) 7.5-minute quadrangle for the study site (Isleton) and the surrounding eight quadrangles: Bouldin Island, Bruceville, Courtland, Jersey Island, Liberty Island, Rio Vista, Terminous, and Thorton.
### Table 3  Environmental Permits Potentially Required for the Georgiana Slough Study Site

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Agency and Permit Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Federal</td>
<td>USACE 408 permission (if project would affect levees in the study site, all of which are USACE project levees), and USACE 404 Permit, Nationwide Permit (if area affected by dredge and fill activities is less than or equal to 0.5 acre of permanent impacts) or Individual Permit (if permanent impacts exceed 0.5 acre)</td>
</tr>
<tr>
<td></td>
<td>USACE Section 10 Rivers and Harbors Act authorization (if structures are a required component of project design)</td>
</tr>
<tr>
<td></td>
<td>Section 106 compliance with National Historic Preservation Act</td>
</tr>
<tr>
<td></td>
<td>Federal ESA compliance (if federal species and critical habitat are present within the study site); consultation with USFWS and NMFS required</td>
</tr>
<tr>
<td>State</td>
<td>RWQCB 401 water quality certification (CEQA compliance required)</td>
</tr>
<tr>
<td></td>
<td>RWQCB NPDES Construction General Permit (if ground disturbance is greater than 1 acre)</td>
</tr>
<tr>
<td></td>
<td>CDFW LSAA (CEQA and CESA compliance required)</td>
</tr>
<tr>
<td></td>
<td>CSLC Lease (the project may be covered under existing MOU)</td>
</tr>
<tr>
<td></td>
<td>Central Valley Flood Protection Board Encroachment Permit</td>
</tr>
<tr>
<td></td>
<td>Delta Stewardship Council Consistency Determination</td>
</tr>
<tr>
<td>Regional and Local</td>
<td>Reclamation District No. 0003, No. 0554, and No. 0556 Encroachment Permits</td>
</tr>
<tr>
<td></td>
<td>Sacramento County Grading Permit (if clearing and grubbing exceed 1 acre or fill exceeds 350 cubic yards of material); Sacramento County Tree Permit (if tree removal or trimming of any tree located on public premises occurs)</td>
</tr>
</tbody>
</table>

Notes: CDFW = California Department of Fish and Wildlife; CEQA = California Environmental Quality Act; CESA = California Endangered Species Act; CSLC = California State Lands Commission; ESA = Endangered Species Act; LSAA = Lake or Streambed Alteration Agreement; MOU = Memorandum of Understanding; NMFS = National Marine Fisheries Service; NPDES = National Pollutant Discharge Elimination System; RWQCB = Regional Water Quality Control Board; USACE = U.S. Army Corps of Engineers; USFWS = U.S. Fish and Wildlife Service.
Memorandum

To: Bill McLaughlin, Senior Engineer, California Department of Water Resources
From: Jennifer Aranda, Senior Project Manager, AECOM
Date: August 22, 2014
Subject: Preliminary Environmental Evaluation of the Threemile Slough Study Site

AECOM technical staff conducted a preliminary evaluation of the Threemile Slough study site under consideration for engineering solutions to reduce diversion of emigrating juvenile salmonids to the interior and southern portions of the Sacramento–San Joaquin Delta (Delta), and to reduce salmonid exposure to Central Valley Project and State Water Project export facilities.

METHODS

A preliminary list of potential environmental issues associated with the Threemile Slough study site is presented in Table 1. AECOM evaluated the study site within the boundary that was provided by the California Department of Water Resources (DWR) (Figure 1); site access, staging areas, and materials stockpile areas were not identified outside the site boundary, and therefore were not assessed for potential environmental issues. Potentially significant environmental issues have been identified that would require further evaluation before beginning final project design because they may influence project design, timing, and project construction options. In addition, informal consultation with the National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), U.S. Army Corps of Engineers (USACE), Central Valley Regional Water Quality Control Board (RWQCB), and California Department of Fish and Wildlife (CDFW) should occur before final project design. This informal consultation would help identify the in-channel construction period and would help develop mitigation and avoidance measures to minimize short-term construction-related impacts on species protected under the federal Endangered Species Act (ESA) and California Endangered Species Act (CESA).

BIOLOGICAL RESOURCES

The sensitive species included in Table 2 are known to occur in the study site vicinity, and suitable habitat for the species may be present within the study site, based on a review of aerial photography and limited site access. Special-status fish species are known to occur within the study site and have the potential to be directly affected by project implementation. Furthermore, field surveys would be required for special-status plants because three species of rare plants—Mason’s lilaeopsis, Delta mudwort, and Suisun marsh aster—are known to occur along the banks of Threemile Slough. Surveys for special-status plants should be timed to coincide with the blooming period (see notes in Table 2) of target species. The preliminary site evaluation suggests that the trees along the waterways would provide suitable nest locations for Swainson’s hawk and white-tailed kite, and foraging habitat is present in the grasslands along the north bank and in the agricultural fields along the south bank. Burrowing owl is known to occur at Brannan Island State Park, in close proximity to the study site. Surveys should be conducted for burrowing owl if implementation of the project may alter habitat for this species. An occurrence of the song sparrow “Modesto” population is known to occur on Decker Island, south of the study site along the Sacramento River. This species was included in Table 2 because of a known occurrence in close proximity to the
Figure 1. Location Map
study site; however, the study site lacks the tule, cattail, and willow thickets this species favors. Avoidance and minimization measures should be developed for all special-status species that have the potential to occur within the study site, as well as including these measures as “environmental commitments” as part of the project description or as mitigation measures for any potentially significant impacts.

**Cultural Resources**

Bridge #240121 (shown on Figure 1) previously was determined eligible for the National Register of Historic Places (NRHP). The bridge should be assessed for any potential indirect project-related impacts. The levee system on Sherman Island was evaluated by AECOM in 2013, and was recommended as not eligible for the NRHP or the California Register of Historical Resources (CRHR). In 2003, one building on assessor parcel number (APN) 158-001-0054-0000 was evaluated for the NRHP and the CRHR, and was recommended as not eligible. If concurrence was received from the State Historic Preservation Officer (SHPO), the building would not need to be reassessed. If concurrence was not received, the building would need to reassessed for the NRHP and the CRHR. The remaining agricultural and residential-type buildings within the study site are more than 50 years old and would require evaluation to determine their eligibility for inclusion in the NRHP and the CRHR.

**Permits and Authorizations**

Work at the Threemile Slough study site may require permits or authorizations from federal, state, and regional and local agencies with regulatory jurisdiction over the environmental resources that are present (Table 3). USACE 408 permission would be required if the project would affect the levees in the study site, all of which are USACE project levees. The project would require a permit (Nationwide or Individual) from USACE under Section 404 of the Clean Water Act (CWA), if project implementation requires the placement of dredge and fill materials into waters of the United States. An Individual Permit and CWA Section 404(b)(1) alternatives analysis are required if permanent wetland impacts exceed the 0.5 acre threshold of the Nationwide Permit program. Impacts on waters of the United States may require implementation of mitigation measures. Compliance with Section 106 of the National Historic Preservation Act would be required to obtain a Section 404 permit. Placement of structures in navigable waterways would require authorization from USACE under Section 10 of the Rivers and Harbors Act of 1899.

The 404 permit would provide the federal nexus for an ESA Section 7 consultation. Formal ESA consultation requires up to 135 days for agency review after project design, timing, and avoidance and mitigation measures have been identified. However, USFWS has recently acknowledged achieving the 135-day consultation timeline may no longer be possible for all projects, especially for projects without multi-benefits. As a result, USFWS is prioritizing workload and not all projects will conclude formal ESA consultation within 135 days. High-level discussion with USFWS will be needed to expedite ESA compliance. Consultation with NMFS would also be required because of potential impacts to anadromous fish. A Rivers and Harbors Act Section 9 Permit may be required from the U.S. Coast Guard. Compliance with the National Environmental Policy Act (NEPA) would be required if any federal funding is used by the project.

Water quality certification from the Central Valley RWQCB would be required for compliance with Section 401 of the CWA. This certification would identify project-specific best management practices (BMPs) to minimize project impacts, such as criteria to reduce erosion, sedimentation, and releases of hazardous material. BMPs also would provide criteria for dewatering and construction methods, revegetation, and monitoring requirements. A National Pollutant Discharge Elimination System (NPDES) Construction General Permit for discharges of stormwater associated with the construction activity would be required if
total soil disturbance exceeds 1 acre. Soil disturbance typically occurs from access improvements, staging areas, material stockpile areas, and construction areas.

A Lake and Streambed Alteration Agreement (LSAA) would be required from CDFW under Section 1600 et seq. of the California Fish and Game Code, to address potential project-related impacts on the bed, banks, and channel of any natural stream and associated riparian vegetation. Both water quality certification and the LSAA would require evidence of compliance with the California Environmental Quality Act (CEQA) before issuance of permits.

Species protected under CESA could occur within the study site or in the study site vicinity. If the potential exists for the project to result in “take” (i.e., kill) of a special-status species that is protected under CESA, an incidental take permit would be required from CDFW. Typically, avoidance and minimization measures can be implemented before project construction to avoid the direct mortality of species protected under CESA.

Encroachment permits may need to be obtained from the Central Valley Flood Protection Board and Reclamation District No. 0341. DWR has a Memorandum of Understanding (MOU) with the California State Lands Commission (CSLC) that became effective on October 19, 1979. DWR is authorized to perform certain types of activities without obtaining a lease from CSLC. The project would need to be evaluated further for compliance with the lease after detailed, project-specific information is available.

A portion of the study site at Three Mile Slough falls within Brannan Island State Park, along the north bank of the channel. An MOU may need to be developed between DWR and the California Department of Parks and Recreation for use of study site land within Brannan Island State Park.

An encroachment permit from California Department of Transportation (Caltrans) may be needed for work on or near State Route 160.

The project may require a consistency determination from the Delta Stewardship Council, if the project achieves the criteria of a “covered action” and “will have a significant [positive or negative] impact on the achievement of one or both of the coequal goals or the implementation of government-sponsored flood control programs to reduce risks to people, property, and state interests in the Delta.” The coequal goals are: (1) providing a more reliable water supply for California; and (2) protecting, restoring, and enhancing the Delta ecosystem.

A Sacramento County grading permit may be required if clearing and grubbing exceed 1 acre or fill exceeds 350 cubic yards of material. A Sacramento County tree permit may be required if tree removal or trimming of any tree located on public premises is proposed.

If you have any questions about the information provided or need additional information, please contact me at (916) 414-5858, or by e-mail (jennifer.aranda@aecom.com).
Table 1  Potential Environmental Issues Associated with the Threemile Slough Study Site

<table>
<thead>
<tr>
<th>Environmental Issue Area</th>
<th>Preliminary Evaluation Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aesthetics</td>
<td>Potential short-term impacts on State Route 160, officially designated as a State Scenic Highway, may require a Caltrans encroachment permit. DWR should coordinate with the U.S. Coast Guard on the positioning of any in-water lights, navigational buoys and signage; and should remove all equipment, lights, buoys, and signage at the end of the project.</td>
</tr>
<tr>
<td>Agriculture and Forestry Resources</td>
<td>Temporary construction-related impacts may occur if agricultural lands are used for staging or materials storage. There are no forestry resources on site.</td>
</tr>
<tr>
<td>Air Quality</td>
<td>Short-term impacts from construction emissions (from construction equipment and vehicles, or fugitive dust) may require mitigation measures to minimize emissions.</td>
</tr>
<tr>
<td>Biological Resources</td>
<td>Potentially significant ESA and CESA take issues related to construction activities, including in-channel work and dewatering activities, may occur.</td>
</tr>
<tr>
<td>Cultural Resources</td>
<td>Assessment for potential indirect impacts on Bridge #240121 would be required. Assessment of the historical significance of buildings more than 50 years old would be required. Potential reassessment of a previously evaluated building should occur if SHPO concurrence was not received for that evaluation. Potential impacts on cultural resources are unlikely; however, the project would require an inventory and evaluation by a cultural resources specialist for permitting. The study site is not considered to be paleontologically sensitive, and therefore no impacts to this resource would occur.</td>
</tr>
<tr>
<td>Environmental Justice</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Geology and Soils</td>
<td>Short-term construction-related erosion could result in sediment transport from land into Threemile Slough, and short-term water-based construction could increase turbidity in the channel. Mitigation measures will be required to prevent erosion and decrease turbidity. Construction in unstable soils, subsidence, and liquefaction could represent hazards; however, these issues could be addressed during the engineering phase of project design.</td>
</tr>
<tr>
<td>Greenhouse Gas Emissions</td>
<td>Short-term construction-related greenhouse gas emissions may occur, but they are not likely to exceed the greenhouse gas thresholds developed by DWR.</td>
</tr>
<tr>
<td>Hazards and Hazardous Materials</td>
<td>A potential risk exists for release of hazardous materials (e.g., cement, fuel, or lubricants) associated with the project. DWR should design the project to minimize risk. DWR may be required to implement a hazardous materials management program.</td>
</tr>
<tr>
<td>Hydrology and Water Quality</td>
<td>Potential short-term impacts on water quality may occur during project construction and operation. Potential changes to water turbidity, stage, and velocity also may occur during project construction and operation. DWR will need to implement avoidance and mitigation measures to protect water quality and monitor turbidity.</td>
</tr>
<tr>
<td>Land Use and Planning</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Mineral Resources</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Noise</td>
<td>Short-term construction-related impacts may occur. DWR should limit construction to daytime hours and employ noise-reducing construction practices.</td>
</tr>
<tr>
<td>Population and Housing</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Public Health and Safety</td>
<td>Construction activities may temporarily affect public health from the potential release of hazardous materials associated with the project. DWR may be required to implement a hazardous materials management program.</td>
</tr>
<tr>
<td>Public Services</td>
<td>A potential short-term impact on U.S. Coast Guard response time may occur if access from Rio Vista Station to the San Joaquin River is impeded. The project design should maintain navigation within the study site.</td>
</tr>
<tr>
<td>Recreation</td>
<td>Potential short-term impacts to Brannan Island State Recreation Area, and boating and related recreational activities within the study site, particularly during the daytime in summer. Maintain navigation and coordinate with U.S. Coast Guard on the positioning of any in-water lights, navigational buoys, and signage.</td>
</tr>
<tr>
<td>Transportation and Traffic</td>
<td>Potential short-term impacts may occur on State Route 160 and the State Route 160 drawbridge; this may require a Caltrans encroachment permit. Potential short-term navigation impacts also may occur; thus, the project design should maintain navigation and DWR should coordinate with the U.S. Coast Guard on the positioning of any in-water lights, navigational buoys, and signage.</td>
</tr>
<tr>
<td>Utilities and Service Systems</td>
<td>No issues or impacts have been identified.</td>
</tr>
</tbody>
</table>

Notes: Caltrans = California Department of Transportation; CESA = California Endangered Species Act; DWR = California Department of Water Resources; ESA = Endangered Species Act; SHPO = State Historic Preservation Office
### Table 2  Potentially Occurring State and Federally Listed Species in the Threemile Slough Study Site Vicinity

<table>
<thead>
<tr>
<th>Class</th>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plants</td>
<td><strong>Hibiscus lasiocarpos var. occidentalis</strong>&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Wooly rose mallow</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td>Plants</td>
<td><strong>Lathyrus jepsonii var. jepsonii</strong>&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Delta tule pea</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td>Plants</td>
<td><strong>Lilaeopsis masonii</strong>&lt;sup&gt;1, 4&lt;/sup&gt;</td>
<td>Mason’s lilaeopsis</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td>Plants</td>
<td><strong>Limosella australis</strong>&lt;sup&gt;1, 5&lt;/sup&gt;</td>
<td>Delta mudwort</td>
<td>CRPR 2</td>
</tr>
<tr>
<td>Plants</td>
<td><strong>Sagittaria sanfordii</strong></td>
<td>Sanford’s arrowhead</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td>Plants</td>
<td><strong>Symphyotrichum lentum</strong>&lt;sup&gt;1, 6&lt;/sup&gt;</td>
<td>Suisun marsh aster</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td>Invertebrates</td>
<td><strong>Desmocerus californicus dimorphus</strong></td>
<td>Valley elderberry longhorn beetle</td>
<td>FT</td>
</tr>
<tr>
<td>Fish</td>
<td><strong>Acipenser medirostris</strong></td>
<td>Green sturgeon (southern DPS)</td>
<td>FT</td>
</tr>
<tr>
<td>Fish</td>
<td><strong>Hypomesus transpacificus</strong>&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Delta smelt</td>
<td>FT, FX, CE</td>
</tr>
<tr>
<td>Fish</td>
<td><strong>Oncorhyncus tsawytscha</strong></td>
<td>Sacramento River winter-run Chinook salmon</td>
<td>FE, FX, CE</td>
</tr>
<tr>
<td>Fish</td>
<td><strong>Oncorhyncus tsawytscha</strong></td>
<td>Central Valley spring-run Chinook salmon</td>
<td>FT, FX, CT</td>
</tr>
<tr>
<td>Fish</td>
<td><strong>Oncorhyncus mykiss</strong>&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Central Valley steelhead DPS</td>
<td>FT, FX, CE</td>
</tr>
<tr>
<td>Fish</td>
<td><strong>Pogonichthys macrolepidotus</strong></td>
<td>Sacramento splittail</td>
<td>SSC</td>
</tr>
<tr>
<td>Fish</td>
<td><strong>Spinichthys thaleichthys</strong>&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Longfin smelt</td>
<td>FC, CT, SSC</td>
</tr>
<tr>
<td>Amphibians</td>
<td><strong>Emys marmorata</strong></td>
<td>Western pond turtle</td>
<td>SSC</td>
</tr>
<tr>
<td>Birds</td>
<td><strong>Athene cunicularia</strong></td>
<td>Burrowing owl</td>
<td>SSC</td>
</tr>
<tr>
<td>Birds</td>
<td><strong>Buteo swainsoni</strong></td>
<td>Swainson’s hawk</td>
<td>CT</td>
</tr>
<tr>
<td>Birds</td>
<td><strong>Elanus leucurus</strong></td>
<td>White-tailed kite</td>
<td>FP</td>
</tr>
<tr>
<td>Birds</td>
<td><strong>Melospiza melodia</strong></td>
<td>Song sparrow “Modesto” population</td>
<td>SSC</td>
</tr>
<tr>
<td>Mammals</td>
<td><strong>Lasiurus blossevillii</strong></td>
<td>Western red bat</td>
<td>SSC</td>
</tr>
</tbody>
</table>

Notes: DPS = distinct population segment

<sup>1</sup> Known to occur within the study site; <sup>2</sup> Blooming Period: June-September; <sup>3</sup> Blooming Period: May-September; <sup>4</sup> Blooming Period: April-November; <sup>5</sup> Blooming Period: May-August; <sup>6</sup> Blooming Period: May-November

Status Notes:

**U.S. Fish and Wildlife Service (USFWS):**

FE = Endangered (legally protected)
FT = Listed as threatened under the federal Endangered Species Act
FC = Candidate for listing under the federal Endangered Species Act
FX = Critical Habitat

**California Department of Fish and Wildlife (CDFW):**

CE = Endangered (legally protected)
FP = Fully protected species—may not be taken or possessed without a permit from the Fish and Game Commission
SSC = California Species of Special Concern
CT = Threatened (legally protected)

**California Native Plant Society:**

CRPR 1B = Plant species considered rare or endangered in California and elsewhere (protected under the California Environmental Quality Act, but not legally protected under the Endangered Species Act or California Endangered Species Act)
CRPR 2 = Plant species considered rare or endangered in California but more common elsewhere (protected under the California Environmental Quality Act, but not legally protected under the Endangered Species Act or California Endangered Species Act)

Search Criteria: Database searches were conducted using the USFWS online database, CDFW’s California Natural Diversity Database (CNDDB), and California Native Plant Society’s (CNPS) Inventory of Rare and Endangered Plants of California to identify sensitive species that could occur in the study site. The database searches included the U.S. Geological Survey (USGS) 7.5-minute quadrangle for the study site (Jersey Island) and the surrounding eight quadrangles: Antioch North, Antioch South, Birds Landing, Bouldin Island, Brentwood, Isleton, Rio Vista, and Woodward Island.
Table 3  Environmental Permits Potentially Required for the Threemile Slough Study Site

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Agency and Permit Type</th>
</tr>
</thead>
</table>
| Federal               | USACE 408 permission (if project would affect levees in the study site, all of which are USACE project levees), and USACE 404 Permit, Nationwide Permit (if area affected by dredge and fill activities is less than or equal to 0.5 acre of permanent impacts) or Individual Permit (if permanent impacts exceed 0.5 acre)  
USACE Section 10 Rivers and Harbors Act authorization (if structures are a required component of project design)  
Section 106 compliance with National Historic Preservation Act  
Federal ESA compliance (if federal species and critical habitat are present within the study site); consultation with USFWS and NMFS required  
U.S. Coast Guard Rivers and Harbors Act Section 9 Permit |
| State                 | RWQCB 401 water quality certification (CEQA compliance required)  
RWQCB NPDES Construction General Permit (if ground disturbance is greater than 1 acre)  
CDFW LSAA (CEQA CESA compliance required)  
CDFL Lease (the project may be covered under existing MOU)  
Central Valley Flood Protection Board Encroachment Permit  
California Department of Parks and Recreation MOU  
Delta Stewardship Council Consistency Determination |
| Regional and Local    | Reclamation District No. 0341 Encroachment Permit  
Sacramento County Grading Permit (if clearing and grubbing exceed 1 acre or fill exceeds 350 cubic yards of material); Sacramento County Tree Permit (if tree removal or trimming of any tree located on public premises) |

Notes: CDFW = California Department of Fish and Wildlife; CEQA = California Environmental Quality Act; CESA = California Endangered Species Act; CSLC = California State Lands Commission; ESA = Endangered Species Act; LSAA = Lake or Streambed Alteration Agreement; MOU = Memorandum of Understanding; NMFS = National Marine Fisheries Service; NPDES = National Pollutant Discharge Elimination System; RWQCB = Regional Water Quality Control Board; USACE = U.S. Army Corps of Engineers; USFWS = U.S. Fish and Wildlife Service
Memorandum

To: Bill McLaughlin, Senior Engineer, California Department of Water Resources
From: Jennifer Aranda, Senior Project Manager, AECOM
Date: August 22, 2014
Subject: Preliminary Environmental Evaluation of the Head of Old River Study Site

AECOM technical staff conducted a preliminary evaluation of the Head of Old River study site under consideration for engineering solutions to reduce diversion of emigrating juvenile salmonids to the interior and southern portions of the Sacramento–San Joaquin Delta (Delta), and to reduce salmonid exposure to Central Valley Project and State Water Project export facilities.

**METHODS**

A preliminary list of potential environmental issues associated with the Head of Old River study site is presented in Table 1. AECOM evaluated the study site within the boundary that was provided by the California Department of Water Resources (DWR) (Figure 1); site access, staging areas, and materials stockpile areas were not identified outside the site boundary, and therefore were not assessed for potential environmental issues. Potentially significant environmental issues have been identified that would require further evaluation before beginning final project design because they may influence project design, timing, and project construction options. In addition, informal consultation with the National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), U.S. Army Corps of Engineers (USACE), Central Valley Regional Water Quality Control Board (RWQCB), and California Department of Fish and Wildlife (CDFW) should occur before final project design. This informal consultation would help identify the in-channel construction period and would help develop mitigation and avoidance measures to minimize short-term construction-related impacts on species protected under the federal Endangered Species Act (ESA) and California Endangered Species Act (CESA).

**BIOLOGICAL RESOURCES**

The sensitive species included in Table 2 are known to occur in the study site vicinity, and suitable habitat for the species may be present within the study site, based on a review of aerial photography and limited site access. Special-status fish species are known to occur within the study site and have the potential to be directly affected by project implementation. Special-status plants are not anticipated to occur at the Head of Old River study site because uplands areas have been heavily altered for agricultural land use and have historically been the site of the annual spring and fall temporary fish barriers, and much of the waterside toes of the levees are armored with riprap. The preliminary site evaluation suggests that the trees along the waterways provide suitable nest locations for Swainson’s hawk and white-tailed kite, and foraging habitat is present in the agricultural lands surrounding the study site. Avoidance and minimization measures should be developed for all special-status species that have the potential to occur within the study site, as well as including these measures as "environmental commitments" as part of the project description or as mitigation measures for any potentially significant impacts.
Figure 1. Location Map
CULTURAL RESOURCES

The levees within the boundary of the study site previously were evaluated for the National Register of Historic Places and the California Register of Historical Resources, and were recommended as not eligible. That determination was concurred with by the State Historic Preservation Officer in 2006.

PERMITS AND AUTHORIZATIONS

Work at the Head of Old River study site may require permits or authorizations from federal, state, and regional and local agencies with regulatory jurisdiction over the environmental resources that are present (Table 3). USACE 408 permission would be required if the project would affect the levees in the study site, all of which are USACE project levees. DWR may need a permit ( Nationwide or Individual) from USACE under Section 404 of the Clean Water Act (CWA), if project implementation requires placement of dredge and fill materials into waters of the United States. An Individual Permit and CWA Section 404(b)(1) alternatives analysis are required if permanent wetland impacts exceed the 0.5 acre threshold of the Nationwide Permit program. Impacts on waters of the United States may require implementation of mitigation measures. Compliance with Section 106 of the National Historic Preservation Act would be required to obtain a Section 404 permit. Placement of structures in navigable waterways would require authorization from USACE under Section 10 of the Rivers and Harbors Act of 1899.

The 404 permit would provide the federal nexus for an ESA Section 7 consultation. Formal ESA consultation requires up to 135 days for agency review after project design, timing, and avoidance and mitigation measures have been identified. However, USFWS has recently acknowledged achieving the 135-day consultation timeline may no longer be possible for all projects, especially for projects without multi-benefits. As a result, USFWS is prioritizing workload and not all projects will conclude formal ESA consultation within 135 days. High-level discussion with USFWS will be needed to expedite ESA compliance. Consultation with NMFS would also be required because of potential impacts to anadromous fish. Compliance with the National Environmental Policy Act (NEPA) would be required if any federal funding is used by the project.

Water quality certification from the Central Valley RWQCB would be required for compliance with Section 401 of the CWA. This certification would identify project-specific best management practices (BMPs) to minimize project impacts, such as criteria to reduce erosion, sedimentation, and releases of hazardous material. BMPs also would provide criteria for dewatering and construction methods, revegetation, and monitoring requirements. A National Pollutant Discharge Elimination System (NPDES) Construction General Permit for discharges of stormwater associated with the construction activity would be required if total soil disturbance exceeds 1 acre. Soil disturbance typically occurs from access improvements, staging areas, material stockpile areas, and construction areas.

A Lake and Streambed Alteration Agreement (LSAA) would be required from CDFW under Section 1600 et seq. of the California Fish and Game Code, to address potential project-related impacts on the bed, banks, and channel of any natural stream and associated riparian vegetation. Both water quality certification and the LSAA would require evidence of compliance with the California Environmental Quality Act (CEQA) before issuance of permits.

Species protected under CESA could occur within the study site or in the study site vicinity. If the potential exists for the project to result in “take” (i.e., kill) of a special-status species that is protected under CESA, an incidental take permit would be required from CDFW. Typically, avoidance and
minimization measures can be implemented before project construction to avoid the direct mortality of species protected under CESA.

Encroachment permits may need to be obtained from the Central Valley Flood Protection Board and Reclamation District No. 0017, No. 0544, and No. 2062. DWR has a Memorandum of Understanding with the California State Lands Commission (CSLC) that became effective on October 19, 1979. DWR is authorized to perform certain types of activities without obtaining a lease from CSLC. The project would need to be evaluated further for compliance with the lease after detailed, project-specific information is available.

The project may require a consistency determination from the Delta Stewardship Council, if the project achieves the criteria of a “covered action” and “will have a significant [positive or negative] impact on the achievement of one or both of the coequal goals or the implementation of government-sponsored flood control programs to reduce risks to people, property, and state interests in the Delta.” The coequal goals are; (1) providing a more reliable water supply for California; and (2) protecting, restoring, and enhancing the Delta ecosystem.

A San Joaquin County grading permit may be required.

If you have any questions about the information provided or need additional information, please contact me at (916) 414-5858, or by e-mail (jennifer.aranda@aecom.com).

<table>
<thead>
<tr>
<th>Environmental Issue Area</th>
<th>Preliminary Evaluation Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aesthetics</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Agriculture and Forestry Resources</td>
<td>Temporary construction-related impacts may occur if agricultural lands are used for staging or materials storage. There are no forestry resources on site.</td>
</tr>
<tr>
<td>Air Quality</td>
<td>Short-term impacts from construction emissions (from construction equipment and vehicles, or fugitive dust) may require mitigation measures to minimize emissions.</td>
</tr>
<tr>
<td>Biological Resources</td>
<td>Potentially significant ESA and CESA take issues related to construction activities, including in-channel work and dewatering activities, may occur.</td>
</tr>
<tr>
<td>Cultural Resources</td>
<td>No cultural resources issues or impacts have been identified. The study site is not considered to be paleontologically sensitive, and therefore no impacts to this resource would occur.</td>
</tr>
<tr>
<td>Environmental Justice</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Geology and Soils</td>
<td>Short-term construction-related erosion could result in sediment transport from land into Old River or the San Joaquin River, and short-term water-based construction could increase turbidity in the channel. Mitigation measures will be required to prevent erosion and decrease turbidity. Construction in unstable soils, subsidence, and liquefaction could represent hazards; however, these issues could be addressed during the engineering phase of project design.</td>
</tr>
<tr>
<td>Greenhouse Gas Emissions</td>
<td>Short-term construction-related greenhouse gas emissions may occur, but they are not likely to exceed the greenhouse gas thresholds developed by DWR.</td>
</tr>
<tr>
<td>Hazards and Hazardous Materials</td>
<td>A potential risk exists for release of hazardous materials (e.g., cement, fuel, or lubricants) associated with the project. DWR should design the project to minimize risk. DWR may be required to implement a hazardous materials management program.</td>
</tr>
<tr>
<td>Hydrology and Water Quality</td>
<td>Potential short-term impacts on water quality may occur during project construction and operation. Potential changes to water turbidity, stage, and velocity also may occur during project construction and operation. DWR will need to implement avoidance and mitigation measures to protect water quality and monitor turbidity.</td>
</tr>
<tr>
<td>Land Use and Planning</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Mineral Resources</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Noise</td>
<td>Short-term construction-related impacts may occur. DWR should limit construction to daytime hours and employ noise-reducing construction practices.</td>
</tr>
</tbody>
</table>
### Table 1  Potential Environmental Issues Associated with the Head of Old River Study Site

<table>
<thead>
<tr>
<th>Environmental Issue Area</th>
<th>Preliminary Evaluation Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population and Housing</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Public Health and Safety</td>
<td>Construction activities may temporarily affect public health from the potential release of hazardous materials associated with the project. DWR may be required to implement a hazardous materials management program.</td>
</tr>
<tr>
<td>Public Services</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Recreation</td>
<td>Potential short-term impacts may occur on boating and related recreational activities within the study site, particularly during daytime in summer. The project design should maintain navigation and DWR should coordinate with the U.S. Coast Guard on the positioning of any in-water lights, navigational buoys, and signage.</td>
</tr>
<tr>
<td>Transportation and Traffic</td>
<td>The project design should maintain navigation and DWR should coordinate with the U.S. Coast Guard on the positioning of any in-water lights, navigational buoys, and signage.</td>
</tr>
<tr>
<td>Utilities and Service Systems</td>
<td>No issues or impacts have been identified.</td>
</tr>
</tbody>
</table>

Notes: CESA = California Endangered Species Act; CRHR = California Register of Historical Resources; DWR = California Department of Water Resources; ESA = Endangered Species Act; NRHP = National Register of Historic Places.

### Table 2  Potentially Occurring State and Federally Listed Species in the Head of Old River Study Site Vicinity

<table>
<thead>
<tr>
<th>Class</th>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plants</td>
<td>Cirsium crassicaule¹,²</td>
<td>Slough thistle</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td>Invertebrates</td>
<td>Desmocerus californicus dimorphus</td>
<td>Valley elderberry longhorn beetle</td>
<td>FT</td>
</tr>
<tr>
<td>Fish</td>
<td>Acipenser medirostris</td>
<td>Green sturgeon (southern DPS)</td>
<td>FT</td>
</tr>
<tr>
<td></td>
<td>Hypomesus transpacificus</td>
<td>Delta smelt</td>
<td>FT, FX, CE</td>
</tr>
<tr>
<td></td>
<td>Oncorhynchus tshawytscha</td>
<td>Sacramento River winter-run Chinook salmon</td>
<td>FE, FX, CE</td>
</tr>
<tr>
<td></td>
<td>Oncorhynchus tshawytzcha</td>
<td>Central Valley spring-run Chinook salmon</td>
<td>FT, FX, CT</td>
</tr>
<tr>
<td></td>
<td>Oncorhynchus mykiss¹</td>
<td>Central Valley steelhead DPS</td>
<td>FT, FX</td>
</tr>
<tr>
<td></td>
<td>Pogonichthys macrolepidotus</td>
<td>Sacramento splittail</td>
<td>SSC</td>
</tr>
<tr>
<td></td>
<td>Spininichus thaleichthys¹</td>
<td>Longfin smelt</td>
<td>FC, CT, SSC</td>
</tr>
<tr>
<td>Amphibians</td>
<td>Emys marmorata</td>
<td>Western pond turtle</td>
<td>SSC</td>
</tr>
<tr>
<td>Birds</td>
<td>Buteo swainsoni¹</td>
<td>Swainson’s hawk</td>
<td>CT</td>
</tr>
<tr>
<td></td>
<td>Elanus leucurus</td>
<td>White-tailed kite</td>
<td>FP</td>
</tr>
<tr>
<td></td>
<td>Melospiza melodia</td>
<td>Song sparrow &quot;Modesto&quot; population</td>
<td>SSC</td>
</tr>
<tr>
<td>Mammals</td>
<td>Lasius blossevillii</td>
<td>Western red bat</td>
<td>SSC</td>
</tr>
</tbody>
</table>

Notes: DPS = distinct population segment
1 Known to occur within the study site; 2 Blooming Period: June-September

Status Notes:

**U.S. Fish and Wildlife Service (USFWS):**

FE = Endangered (legally protected)
FT = Listed as threatened under the federal Endangered Species Act
FC = Candidate for listing under the federal Endangered Species Act
FX = Critical Habitat

**California Department of Fish and Wildlife (CDFW):**

CE = Endangered (legally protected)
FP = Fully protected species—may not be taken or possessed without a permit from the Fish and Game Commission
SSC = California Species of Special Concern
CT = Threatened (legally protected)

**California Native Plant Society:**

CRPR 1A = Plant species presumed extinct in California
Table 2  Potentially Occurring State and Federally Listed Species in the Head of Old River Study Site Vicinity

| CRPR 1B | Plant species considered rare or endangered in California and elsewhere (protected under the California Environmental Quality Act, but not legally protected under the Endangered Species Act or California Endangered Species Act) |
| CRPR 2 | Plant species considered rare or endangered in California but more common elsewhere (protected under the California Environmental Quality Act, but not legally protected under the Endangered Species Act or California Endangered Species Act) |

Search Criteria: Database searches were conducted using the USFWS online database (USFWS 2014), CDFW’s California Natural Diversity Database (CNDDB), and California Native Plant Society’s (CNPS) Inventory of Rare and Endangered Plants of California to identify sensitive species that could occur in the study site. The database searches included the U.S. Geological Survey (USGS) 7.5-minute quadrangle for the study site (Lathrop) and the surrounding eight quadrangles: Holt, Manteca, Ripon, Stockton East, Stockton West, Tracy, Union Island, and Vernalis.

Table 3  Environmental Permits Potentially Required for the Head of Old River Study Site

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Agency and Permit Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Federal</td>
<td>USACE 408 permission (if project would affect levees in the study site, all of which are USACE project levees), and 404 Permit, Nationwide Permit (if area affected by dredge and fill activities is less than or equal to 0.5 acre of permanent impacts) or Individual Permit (if permanent impacts exceed 0.5 acre)</td>
</tr>
<tr>
<td></td>
<td>USACE Section 10 Rivers and Harbors Act authorization (if structures are a required component of project design)</td>
</tr>
<tr>
<td></td>
<td>Section 106 compliance with National Historic Preservation Act</td>
</tr>
<tr>
<td></td>
<td>Federal ESA compliance (if federal species and critical habitat are present within the study site); consultation with USFWS and NMFS required</td>
</tr>
<tr>
<td>State</td>
<td>RWQCB 401 Water Quality Certification (CEQA compliance required)</td>
</tr>
<tr>
<td></td>
<td>RWQCB NPDES Construction General Permit (if ground disturbance is greater than 1 acre)</td>
</tr>
<tr>
<td></td>
<td>CDFW LSAA (CEQA and CESA compliance required)</td>
</tr>
<tr>
<td></td>
<td>CSLC Lease (the project may be covered under existing MOU)</td>
</tr>
<tr>
<td></td>
<td>Central Valley Flood Protection Board Encroachment Permit</td>
</tr>
<tr>
<td></td>
<td>Delta Stewardship Council Consistency Determination</td>
</tr>
<tr>
<td>Regional and Local</td>
<td>Reclamation District No. 0017, No. 0544, and No. 2062 Encroachment Permits</td>
</tr>
<tr>
<td></td>
<td>San Joaquin County Grading Permit (unless the project is exempt)</td>
</tr>
</tbody>
</table>

Notes: CDFW = California Department of Fish and Wildlife; CEQA = California Environmental Quality Act; CESA = California Endangered Species Act; CSLC = California State Lands Commission; ESA = Endangered Species Act; LSAA = Lake or Streambed Alteration Agreement; MOU = Memorandum of Understanding; NMFS = National Marine Fisheries Service; NPDES = National Pollutant Discharge Elimination System; RWQCB = Regional Water Quality Control Board; USACE = U.S. Army Corps of Engineers; USFWS = U.S. Fish and Wildlife Service
Memorandum

To: Bill McLaughlin, Senior Engineer, California Department of Water Resources
From: Jennifer Aranda, Senior Project Manager, AECOM
Date: August 22, 2014
Subject: Preliminary Environmental Evaluation of the Turner Cut Study Site

AECOM technical staff conducted a preliminary evaluation of the Turner Cut study site under consideration for engineering solutions to reduce diversion of emigrating juvenile salmonids to the interior and southern portions of the Sacramento–San Joaquin Delta (Delta), and to reduce salmonid exposure to Central Valley Project and State Water Project export facilities.

**METHODS**

A preliminary list of potential environmental issues associated with the Turner Cut study site is presented in Table 1. AECOM evaluated the study site within the boundary that was provided by the California Department of Water Resources (DWR)(Figure 1); site access, staging areas, and materials stockpile areas were not identified outside the site boundary, and therefore were not assessed for potential environmental issues. Potentially significant environmental issues have been identified that would require further evaluation before beginning final project design because they may influence project design, timing, and project construction options. In addition, informal consultation with the National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), U.S. Army Corps of Engineers (USACE), Central Valley Regional Water Quality Control Board (RWQCB), and California Department of Fish and Wildlife (CDFW) should occur before final project design. This informal consultation would help identify the in-channel construction period and would help develop mitigation and avoidance measures to minimize short-term construction-related impacts on species protected under the federal Endangered Species Act (ESA) and California Endangered Species Act (CESA).

**BIOLOGICAL RESOURCES**

The sensitive species included in Table 2 are known to occur in the study site vicinity, and suitable habitat for the species may be present within the study site, based on a review of aerial photography. Special-status fish species are known to occur within the study site and have the potential to be directly affected by project implementation. Furthermore, field surveys would be required for special-status plants because two species of rare plants—wooly rose mallow and Suisun marsh aster—are known to occur both up and downstream from the study site. Surveys for special-status plants should be timed to coincide with the blooming period (see notes in Table 2) of target species. The preliminary site evaluation suggests that the trees along the waterways and on Acker Island would provide suitable nest locations for Swainson’s hawk and white-tailed kite, and foraging habitat is present in the agricultural lands surrounding the study site. Avoidance and minimization measures should be developed for all special-status species that have the potential to occur within the study site, as well as including these
measures as “environmental commitments” as part of the project description or as mitigation measures for any potentially significant impacts.

CULTURAL RESOURCES

A commercial building within the study site (shown on Figure 1) is likely 45 years old and would need to be evaluated for the National Register of Historic Places (NRHP) and the California Register of Historical Resources (CRHR). Portions of the levees within the study site also are more than 50 years old, and they also would need to be evaluated to determine their eligibility for the NRHP and the CRHR.

PERMITS AND AUTHORIZATIONS

Work at the Turner Cut study site may require permits or authorizations from federal, state, and regional and local agencies with regulatory jurisdiction over the environmental resources that are present (Table 3). USACE 408 permission would be required if the project would affect the Lower Roberts Island levee, which is a USACE project levee. The project would require a permit (Nationwide or Individual) from USACE under Section 404 of the Clean Water Act (CWA), if project implementation requires the placement of dredge and fill materials into waters of the United States. An Individual Permit and CWA Section 404(b)(1) alternatives analysis are required if permanent wetland impacts exceed the 0.5 acre threshold of the Nationwide Permit program. Impacts on waters of the United States may require implementation of mitigation measures. Compliance with Section 106 of the National Historic Preservation Act would require a Section 404 permit. Placement of structures in navigable waterways would require authorization from USACE under Section 10 of the Rivers and Harbors Act of 1899.

The 404 permit would provide the federal nexus for an ESA Section 7 consultation. Formal ESA consultation requires up to 135 days for agency review after project design, timing, and avoidance and mitigation measures have been identified. However, USFWS has recently acknowledged achieving the 135-day consultation timeline may no longer be possible for all projects, especially for projects without multi-benefits. As a result, USFWS is prioritizing workload and not all projects will conclude formal ESA consultation within 135 days. High-level discussion with USFWS will be needed to expedite ESA compliance. Consultation with NMFS would also be required because of potential impacts to anadromous fish. Compliance with the National Environmental Policy Act (NEPA) would be required if any federal funding is used by the project.

Water quality certification from the Central Valley RWQCB would be required for compliance with Section 401 of the CWA. This certification would identify project-specific best management practices (BMPs) to minimize project impacts, such as criteria to reduce erosion, sedimentation, and releases of hazardous material. BMPs also would provide criteria for dewatering and construction methods, revegetation, and monitoring requirements. A National Pollutant Discharge Elimination System (NPDES) Construction General Permit for discharges of stormwater associated with the construction activity would be required if total soil disturbance exceeds 1 acre. Soil disturbance typically occurs from access improvements, staging areas, material stockpile areas, and construction areas.

A Lake and Streambed Alteration Agreement (LSAA) would be required from CDFW under Section 1600 et seq. of the California Fish and Game Code, to address potential project-related impacts on the bed, banks, and channel of any natural stream and associated riparian vegetation. Both Water Quality Certification and the LSAA would require evidence of compliance with the California Environmental Quality Act (CEQA) before issuance of permits.
Species protected under CESA could occur within the study site or in the study site vicinity. If the potential exists for the project to result in "take" (i.e., kill) of a special-status species that is protected under CESA, an incidental take permit would be required from CDFW. Typically, avoidance and minimization measures can be implemented before project construction to avoid the direct mortality of species protected under CESA.

Encroachment permits may need to be obtained from the Central Valley Flood Protection Board and Reclamation District No. 0684 and No. 2030. DWR has a Memorandum of Understanding with the California State Lands Commission (CSLC) that became effective on October 19, 1979. DWR is authorized to perform certain types of activities without obtaining a lease from CSLC. The project would need to be evaluated further for compliance with the lease after detailed project-specific information is available.

The project may require a consistency determination from the Delta Stewardship Council, if the project achieves the criteria of a “covered action” and “will have a significant [positive or negative] impact on the achievement of one or both of the coequal goals or the implementation of government-sponsored flood control programs to reduce risks to people, property, and state interests in the Delta.” The coequal goals are: (1) providing a more reliable water supply for California; and (2) protecting, restoring, and enhancing the Delta ecosystem.

A San Joaquin County grading permit may be required, unless the project is exempt.

If you have any questions about the information provided or need additional information, please contact me at (916) 414-5858, or by e-mail (jennifer.aranda@aecom.com).

Table 1  Potential Environmental Issues Associated with the Turner Cut Study Site

<table>
<thead>
<tr>
<th>Environmental Issue Area</th>
<th>Preliminary Evaluation Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aesthetics</td>
<td>DWR should coordinate with the U.S. Coast Guard on the positioning of any in-water lights, navigational buoys, and signage; and should remove all equipment, lights, buoys, and signage at the end of the project.</td>
</tr>
<tr>
<td>Agriculture and Forestry Resources</td>
<td>Temporary construction-related impacts may occur if agricultural lands are used for staging or materials storage. There are no forestry resources on site.</td>
</tr>
<tr>
<td>Air Quality</td>
<td>Short-term impacts from construction emissions (from construction equipment and vehicles, or fugitive dust) may require mitigation measures to minimize emissions.</td>
</tr>
<tr>
<td>Biological Resources</td>
<td>Potentially significant ESA and CESA take issues related to construction activities, including in-channel work and dewatering activities, may occur.</td>
</tr>
<tr>
<td>Cultural Resources</td>
<td>Assessment of the historical significance of the levees and buildings 45 years and older would be required. Potential impacts on cultural resources are unlikely; however, the project would require an inventory and an evaluation by a cultural resources specialist for permitting. The study site is not considered to be paleontologically sensitive, and therefore no impacts to this resource would occur.</td>
</tr>
<tr>
<td>Environmental Justice</td>
<td>No impacts or issues have been identified.</td>
</tr>
<tr>
<td>Geology and Soils</td>
<td>Short-term construction-related erosion could result in sediment transport from land into Turner Cut or the adjacent river channels, and short-term water-based construction could increase turbidity in the channel. DWR will be required to implement avoidance and mitigation measures to prevent erosion and decrease turbidity. Construction in unstable soils, subsidence, and liquefaction could represent hazards; however, these issues could be addressed during the engineering phase of project design.</td>
</tr>
<tr>
<td>Greenhouse Gas Emissions</td>
<td>Short-term construction-related greenhouse gas emissions may occur, but they are not likely to exceed the greenhouse gas thresholds developed by DWR.</td>
</tr>
<tr>
<td>Hazards and Hazardous Materials</td>
<td>A potential risk exists for release of hazardous materials (e.g., cement, fuel, or lubricants) associated with the project. DWR should design the project to minimize risk. DWR may be required to implement a hazardous materials management program.</td>
</tr>
</tbody>
</table>
Table 1  Potential Environmental Issues Associated with the Turner Cut Study Site

<table>
<thead>
<tr>
<th>Environmental Issue Area</th>
<th>Preliminary Evaluation Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrology and Water Quality</td>
<td>Potential short-term impacts on water quality may occur during project construction and operation. Potential changes to water turbidity, stage, and velocity also may occur during project construction and operation. DWR will need to implement avoidance and mitigation measures to protect water quality and monitor turbidity.</td>
</tr>
<tr>
<td>Land Use and Planning</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Mineral Resources</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Noise</td>
<td>Short-term construction-related impacts may occur. DWR should limit construction to daytime hours and employ noise-reducing construction practices.</td>
</tr>
<tr>
<td>Population and Housing</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Public Health and Safety</td>
<td>Construction activities temporarily may affect public health from the potential release of hazardous materials associated with the project. DWR may be required to implement a hazardous materials management program.</td>
</tr>
<tr>
<td>Public Services</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Recreation</td>
<td>Potential short-term impacts may occur on marinas at Acker Island, as well as on boating and related recreational activities within the study site, particularly during daytime in summer. DWR should coordinate with the U.S. Coast Guard on the positioning of any in-water lights, navigational buoys, and signage.</td>
</tr>
<tr>
<td>Transportation and Traffic</td>
<td>Potential short-term navigation impacts may occur; access is anticipated to be available to the north of the study site. DWR should coordinate with the U.S. Coast Guard on the positioning of any in-water lights, navigational buoys, and signage.</td>
</tr>
<tr>
<td>Utilities and Service Systems</td>
<td>No issues or impacts have been identified.</td>
</tr>
</tbody>
</table>

Notes: CESA = California Endangered Species Act; DWR = California Department of Water Resources; ESA = Endangered Species Act

Table 2  Potentially Occurring State and Federally Listed Species in the Turner Cut Study Site Vicinity

<table>
<thead>
<tr>
<th>Class</th>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plants</td>
<td>Hibiscus lasiocarpos var. occidentalis&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Wooly rose mallow</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td></td>
<td>Lathyrus jepsonii var. jepsonii&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Delta tule pea</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td></td>
<td>Lilaeopsis masonii&lt;sup&gt;4&lt;/sup&gt;</td>
<td>Mason’s lilaeopsis</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td></td>
<td>Limosella australis&lt;sup&gt;5&lt;/sup&gt;</td>
<td>Delta mudwort</td>
<td>CRPR 2</td>
</tr>
<tr>
<td></td>
<td>Sagittaria sanfordii&lt;sup&gt;6&lt;/sup&gt;</td>
<td>Sanford’s arrowhead</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td></td>
<td>Symphyotrichum lentum&lt;sup&gt;7&lt;/sup&gt;</td>
<td>Suisun marsh aster</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td>Invertebrates</td>
<td>Desmocerus Californicus dimorphus</td>
<td>Valley elderberry longhorn beetle</td>
<td>FT</td>
</tr>
<tr>
<td>Fish</td>
<td>Acipenser medirostris</td>
<td>Green sturgeon (southern DPS)</td>
<td>FT</td>
</tr>
<tr>
<td></td>
<td>Hypomesus transpacificus&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Delta smelt</td>
<td>FT, FX, CE</td>
</tr>
<tr>
<td></td>
<td>Oncorhynchus tshawytscha</td>
<td>Sacramento River winter-run Chinook salmon</td>
<td>FE, FX, CE</td>
</tr>
<tr>
<td></td>
<td>Oncorhynchus tshawytscha</td>
<td>Central Valley spring-run Chinook salmon</td>
<td>FT, FX, CT</td>
</tr>
<tr>
<td></td>
<td>Oncorhynchus mykiss&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Central Valley steelhead DPS</td>
<td>FT, FX</td>
</tr>
<tr>
<td></td>
<td>Pogonichthys macrolepidotus</td>
<td>Sacramento splittail</td>
<td>SSC</td>
</tr>
<tr>
<td></td>
<td>Spinichthys thaleichthys&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Longfin smelt</td>
<td>FC, CT, SSC</td>
</tr>
<tr>
<td>Amphibians</td>
<td>Emys marmorata</td>
<td>Western pond turtle</td>
<td>SSC</td>
</tr>
<tr>
<td>Reptiles</td>
<td>Thamnophis gigas</td>
<td>Giant garter snake</td>
<td>FT, CT</td>
</tr>
<tr>
<td>Birds</td>
<td>Buteo swainsoni</td>
<td>Swainson’s hawk</td>
<td>CT</td>
</tr>
<tr>
<td></td>
<td>Elanus leucurus</td>
<td>White-tailed kite</td>
<td>FP</td>
</tr>
<tr>
<td></td>
<td>Laterallus jamaiensis coturniculus</td>
<td>California black rail</td>
<td>CT, FP</td>
</tr>
<tr>
<td></td>
<td>Melospiza melodia</td>
<td>Song sparrow “Modesto” population</td>
<td>SSC</td>
</tr>
<tr>
<td>Mammals</td>
<td>Lasiurus bossevillii</td>
<td>Western red bat</td>
<td>SSC</td>
</tr>
</tbody>
</table>
Table 2  Potentially Occurring State and Federally Listed Species in the Turner Cut Study Site Vicinity

| Notes: DPS = distinct population segment |
| 1 Known to occur within the study site; 2 Blooming Period: June-September; 3 Blooming Period: May-September; 4 Blooming Period: April-November; 5 Blooming Period: May-August; 6 Blooming Period: May-November |
|  |
| **U.S. Fish and Wildlife Service (USFWS):** |
| FE = Endangered (legally protected) |
| FT = Listed as threatened under the federal Endangered Species Act |
| FC = Candidate for listing under the federal Endangered Species Act |
| FX = Critical Habitat |
| **California Department of Fish and Wildlife (CDFW):** |
| CE = Endangered (legally protected) |
| FP = Fully protected species—may not be taken or possessed without a permit from the Fish and Game Commission |
| SSC = California Species of Special Concern |
| CT = Threatened (legally protected) |
| **California Native Plant Society:** |
| CRPR 1B = Plant species considered rare or endangered in California and elsewhere (protected under the California Environmental Quality Act, but not legally protected under the Endangered Species Act or California Endangered Species Act) |
| CRPR 2 = Plant species considered rare or endangered in California but more common elsewhere (protected under the California Environmental Quality Act, but not legally protected under the Endangered Species Act or California Endangered Species Act) |
| Search Criteria: Database searches were conducted using the USFWS online database, CDFW’s California Natural Diversity Database (CNDDDB), and California Native Plant Society’s (CNPS) Inventory of Rare and Endangered Plants of California to identify sensitive species that could occur in the study site. The database searches included the U.S. Geological Survey (USGS) 7.5-minute quadrangle for the study site (Holt) and the surrounding eight quadrangles: Bouldin Island, Clifton Court Forebay, Lathrop, Lodi South, Stockton West, Terminous, Union Island, and Woodward Island. |

Table 3  Environmental Permits Potentially Required for the Turner Cut Study Site

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Agency and Permit Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Federal</td>
<td>USACE 408 permission (if project would affect the Lower Roberts Island levee, which is a USACE project levee), and USACE 404 Permit, Nationwide Permit (if area affected by dredge and fill activities is less than or equal to 0.5 acre of permanent impacts) or Individual Permit (if permanent impacts exceed 0.5 acre)</td>
</tr>
<tr>
<td></td>
<td>USACE Section 10 Rivers and Harbors Act authorization (if structures are a required component of project design)</td>
</tr>
<tr>
<td></td>
<td>Section 106 compliance with National Historic Preservation Act</td>
</tr>
<tr>
<td></td>
<td>Federal ESA compliance (if federal species and critical habitat are present within the study site); consultation with USFWS and NMFS required</td>
</tr>
<tr>
<td>State</td>
<td>RWQCB 401 water quality certification (CEQA compliance required)</td>
</tr>
<tr>
<td></td>
<td>RWQCB NPDES Construction General Permit (if ground disturbance is greater than 1 acre)</td>
</tr>
<tr>
<td></td>
<td>CDFW LSAA (CEQA and CESA compliance required)</td>
</tr>
<tr>
<td></td>
<td>CSLC Lease (the project may be covered under existing MOU)</td>
</tr>
<tr>
<td></td>
<td>Central Valley Flood Protection Board Encroachment Permit</td>
</tr>
<tr>
<td></td>
<td>Delta Stewardship Council Consistency Determination</td>
</tr>
<tr>
<td>Regional and Local</td>
<td>Reclamation District No. 0684 and No. 2030 Encroachment Permits</td>
</tr>
<tr>
<td></td>
<td>San Joaquin County Grading Permit (unless the project is exempt)</td>
</tr>
</tbody>
</table>

Notes: CDFW = California Department of Fish and Wildlife; CEQA = California Environmental Quality Act; CESA = California Endangered Species Act; CSLC = California State Lands Commission; ESA = Endangered Species Act; LSAA = Lake or Streambed Alteration Agreement; MOU = Memorandum of Understanding; NMFS = National Marine Fisheries Service; NPDES = National Pollutant Discharge Elimination System; RWQCB = Regional Water Quality Control Board; USACE = U.S. Army Corps of Engineers; USFWS = U.S. Fish and Wildlife Service
Memorandum

To: Bill McLaughlin, Senior Engineer, California Department of Water Resources
From: Jennifer Aranda, Senior Project Manager, AECOM
Date: August 22, 2014
Subject: Preliminary Environmental Evaluation of the Columbia Cut Study Site

AECOM technical staff conducted a preliminary evaluation of the Columbia Cut study site under consideration for engineering solutions to reduce diversion of emigrating juvenile salmonids to the interior and southern portions of the Sacramento–San Joaquin Delta (Delta), and to reduce salmonid exposure to Central Valley Project and State Water Project export facilities.

METHODS

A preliminary list of potential environmental issues associated with the Columbia Cut study site is presented in Table 1. AECOM evaluated the study site within the boundary that was provided by the California Department of Water Resources (DWR) (Figure 1); site access, staging areas, and materials stockpile areas were not identified outside the site boundary, and therefore were not assessed for potential environmental issues. Potentially significant environmental issues have been identified that would require further evaluation before beginning final project design because they may influence project design, timing, and project construction options. In addition, informal consultation with the National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), U.S. Army Corps of Engineers (USACE), Central Valley Regional Water Quality Control Board (RWQCB), and California Department of Fish and Wildlife (CDFW) should occur before final project design. This informal consultation would help identify the in-channel construction period and would help develop mitigation and avoidance measures to minimize short-term construction-related impacts on species protected under the federal Endangered Species Act (ESA) and California Endangered Species Act (CESA).

BIOLOGICAL RESOURCES

The sensitive species included in Table 2 are known to occur in the study site vicinity, and suitable habitat for the species may be present within the study site, based on a review of aerial photography. Special-status fish species are known to occur within the study site and have the potential to be directly affected by project implementation. Furthermore, field surveys would be required for special-status plants because five species of rare plants—Mason's lilaeopsis, Delta mudwort, wooly rose mallow, Suisun marsh aster, and Delta tule pea—are known to occur along the banks of Columbia Cut within the study site, or in close proximity. Surveys for special-status plants should be timed to coincide with the blooming period (see notes in Table 2) of target species. The preliminary site evaluation suggests that the trees along the waterways provide suitable nest locations for Swainson's hawk and white-tailed kite, and foraging habitat is present in the agricultural lands surrounding the study site. California black rail also is known to occur on the unnamed island situated between Columbia Cut, Whiskey Slough, and the
San Joaquin River. Avoidance and minimization measures should be developed for all special-status species that have the potential to occur within the study site, as well as including these measures as “environmental commitments” as part of the project description or as mitigation measures for any potentially significant impacts.

**CULTURAL RESOURCES**

The study site has not been inventoried for archaeological resources and would need an archaeological survey completed before beginning construction. The levees are more than 50 years old and would require evaluation for inclusion in the National Register of Historic Places and the California Register of Historical Resources.

**PERMITS AND AUTHORIZATIONS**

Work at the Columbia Cut study site may require permits or authorizations from federal, state, and regional and local agencies with regulatory jurisdiction over the environmental resources that are present (Table 3). USACE 408 permission would be required if the project would affect the McDonald Island levee, which is a USACE project levee. DWR may need a permit (Nationwide or Individual) from USACE under Section 404 of the Clean Water Act (CWA), if project implementation requires placement of dredge and fill materials into waters of the United States. An Individual Permit and CWA Section 404(b)(1) alternatives analysis are required if permanent wetland impacts exceed the 0.5 acre threshold of the Nationwide Permit program. Impacts on waters of the United States may require implementation of mitigation measures. Compliance with Section 106 of the National Historic Preservation Act would be required to obtain a Section 404 permit. Placement of structures in navigable waterways would require authorization from USACE under Section 10 of the Rivers and Harbors Act of 1899.

The 404 permit would provide the federal nexus for an ESA Section 7 consultation. Formal ESA consultation requires up to 135 days for agency review after project design, timing, and avoidance and mitigation measures have been identified. However, USFWS has recently acknowledged achieving the 135-day consultation timeline may no longer be possible for all projects, especially for projects without multi-benefits. As a result, USFWS is prioritizing workload and not all projects will conclude formal ESA consultation within 135 days. High-level discussion with USFWS will be needed to expedite ESA compliance. Consultation with NMFS would also be required because of potential impacts to anadromous fish. Compliance with the National Environmental Policy Act (NEPA) would be required if any federal funding is used by the project.

Water quality certification from the Central Valley RWQCB would be required for compliance with Section 401 of the CWA. This certification would identify project-specific best management practices (BMPs) to minimize project impacts, such as criteria to reduce erosion, sedimentation, and releases of hazardous material. BMPs also would provide criteria for dewatering and construction methods, revegetation, and monitoring requirements. A National Pollutant Discharge Elimination System (NPDES) Construction General Permit for discharges of stormwater associated with the construction activity would be required if total soil disturbance exceeds 1 acre. Soil disturbance typically occurs from access improvements, staging areas, material stockpile areas, and construction areas.

A Lake and Streambed Alteration Agreement (LSAA) would be required from CDFW under Section 1600 et seq. of the California Fish and Game Code, to address potential project-related impacts on the bed, banks, and channel of any natural stream and associated riparian vegetation. Both water quality certification and the LSAA would require evidence of compliance with the California Environmental Quality Act (CEQA) before issuance of permits.
Species protected under CESA could occur within the study site or in the study site vicinity. If the potential exists for the project to result in "take" (i.e., kill) of a special-status species that is protected under CESA, an incidental take permit would be required from CDFW. Typically, avoidance and minimization measures can be implemented before project construction to avoid the direct mortality of species protected under CESA.

Encroachment permits may need to be obtained from the Central Valley Flood Protection Board and Reclamation District No. 2030 and No. 2041. DWR has a Memorandum of Understanding with the California State Lands Commission (CSLC), which became effective on October 19, 1979. DWR is authorized to perform certain types of activities without obtaining a lease from CSLC. The project would need to be evaluated further for compliance with the lease after detailed, project-specific information is available.

The project may require a consistency determination from the Delta Stewardship Council, if the project achieves the criteria of a “covered action” and “will have a significant [positive or negative] impact on the achievement of one or both of the coequal goals or the implementation of government-sponsored flood control programs to reduce risks to people, property, and state interests in the Delta.” The coequal goals are: (1) providing a more reliable water supply for California; and (2) protecting, restoring, and enhancing the Delta ecosystem.

A San Joaquin County grading permit may be required.

If you have any questions about the information or need additional information, please contact me at (916) 414-5858, or by e-mail (jennifer.aranda@aecom.com).

Table 1  Potential Environmental Issues Associated with the Columbia Cut Study Site

<table>
<thead>
<tr>
<th>Environmental Issue Area</th>
<th>Preliminary Evaluation Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aesthetics</td>
<td>DWR would need to coordinate with the U.S. Coast Guard on the positioning of any in-water lights, navigational buoys, and signage, and would have to remove all equipment, lights, buoys, and signage at the end of the project.</td>
</tr>
<tr>
<td>Agriculture and Forestry</td>
<td>Temporary construction-related impacts may occur if agricultural land is used for staging or materials storage. There are no forestry resources on site.</td>
</tr>
<tr>
<td>Resources</td>
<td></td>
</tr>
<tr>
<td>Air Quality</td>
<td>Short-term impacts from construction emissions (from construction equipment and vehicles, or fugitive dust) may require measures to minimize emissions.</td>
</tr>
<tr>
<td>Biological Resources</td>
<td>Potentially significant ESA and CESA take issues related to construction activities, including in-channel work and dewatering activities, may occur.</td>
</tr>
<tr>
<td>Cultural Resources</td>
<td>The study site has not been inventoried for archaeological or built environment resources. Although potential impacts on cultural resources are unlikely, the project will require an inventory and evaluation by a cultural resources specialist for permitting purposes, including an assessment of the NRHP/CRHR significance of the levees. The study site is not considered to be paleontologically sensitive, and therefore no impacts to this resource would.</td>
</tr>
<tr>
<td>Environmental Justice</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Geology and Soils</td>
<td>Short-term construction-related erosion could result in sediment transport from land into Columbia Cut or the adjacent river channels, and short-term water-based construction could increase turbidity in the channel. Mitigation measures will be required to prevent erosion and decrease turbidity. Construction in unstable soils, subsidence, and liquefaction could represent hazards; however, these issues could be addressed during the engineering phase of project design.</td>
</tr>
<tr>
<td>Greenhouse Gas Emissions</td>
<td>Short-term construction-related greenhouse gas emissions may occur, but they are not likely to exceed the greenhouse gas thresholds developed by DWR.</td>
</tr>
<tr>
<td>Hazards and Hazardous Materials</td>
<td>A potential risk exists for release of hazardous materials (e.g., cement, fuel, or lubricants) associated with the project. DWR should design the project to minimize risk. DWR may be required to implement a hazardous materials management program.</td>
</tr>
</tbody>
</table>
Table 1  Potential Environmental Issues Associated with the Columbia Cut Study Site

<table>
<thead>
<tr>
<th>Environmental Issue Area</th>
<th>Preliminary Evaluation Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrology and Water Quality</td>
<td>Potential short-term impacts on water quality may occur during project construction and operation. Potential changes to water turbidity, stage, and velocity also may occur during project construction and operation. DWR will need to implement avoidance and mitigation measures to protect water quality and monitor turbidity.</td>
</tr>
<tr>
<td>Land Use and Planning</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Mineral Resources</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Noise</td>
<td>Short-term construction-related impacts may occur. DWR should limit construction to daytime hours and employ noise-reducing construction practices.</td>
</tr>
<tr>
<td>Population and Housing</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Public Health and Safety</td>
<td>Construction activities may temporarily affect public health from the potential release of hazardous materials associated with the project. DWR may be required to implement a hazardous materials management program.</td>
</tr>
<tr>
<td>Public Services</td>
<td>No issues or impacts have been identified.</td>
</tr>
<tr>
<td>Recreation</td>
<td>Potential short-term impacts may occur on St. Francis Yacht Club on Tinsley Island, and on other nearby marinas, boating, and related recreational activities within the study site, particularly during daytime in summer. DWR should coordinate with the U.S. Coast Guard on the positioning of any in-water lights, navigational buoys, and signage.</td>
</tr>
<tr>
<td>Transportation and Traffic</td>
<td>Potential short-term navigation impacts may occur; access to the north and south of the study site anticipated to be available. DWR should coordinate with the U.S. Coast Guard on the positioning of any in-water lights, navigational buoys, and signage.</td>
</tr>
<tr>
<td>Utilities and Service Systems</td>
<td>No issues or impacts have been identified.</td>
</tr>
</tbody>
</table>

Notes: CESA = California Endangered Species Act; CRHR = California Register of Historical Resources; DWR = California Department of Water Resources; ESA = Endangered Species Act; NRHP = National Register of Historic Places

Table 2  Potentially Occurring State and Federally Listed Species in the Columbia Cut Study Site Vicinity

<table>
<thead>
<tr>
<th>Class</th>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plants</td>
<td>Hibiscus lasiocarpus var. occidentalis¹, ²</td>
<td>Wooly rose mallow</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td>Plants</td>
<td>Lathyrus jepsonii var. jepsonii³</td>
<td>Delta tule pea</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td>Plants</td>
<td>Lilaeopsis masonii⁴, ⁵</td>
<td>Mason’s lilaeopsis</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td>Plants</td>
<td>Limosella australis⁵, ⁶</td>
<td>Delta mudwort</td>
<td>CRPR 2</td>
</tr>
<tr>
<td>Plants</td>
<td>Sagittaria sandfordii</td>
<td>Sanford’s arrowhead</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td>Plants</td>
<td>Symphyotrichum lentum⁷, ⁸</td>
<td>Suisun marsh aster</td>
<td>CRPR 1B</td>
</tr>
<tr>
<td>Invertebrates</td>
<td>Desmocerus californicus dimorphus</td>
<td>Valley elderberry longhorn beetle</td>
<td>FT</td>
</tr>
<tr>
<td>Fish</td>
<td>Acipenser medirostris</td>
<td>Green sturgeon (southern DPS)</td>
<td>FT</td>
</tr>
<tr>
<td>Fish</td>
<td>Hypomesus transpacificus¹</td>
<td>Delta smelt</td>
<td>FT, FX, CE</td>
</tr>
<tr>
<td>Fish</td>
<td>Oncorhynchus tshawytscha</td>
<td>Sacramento River winter-run Chinook salmon</td>
<td>FE, FX, CE</td>
</tr>
<tr>
<td>Fish</td>
<td>Oncorhynchus tshawytscha</td>
<td>Central Valley spring-run Chinook salmon</td>
<td>FT, FX, CT</td>
</tr>
<tr>
<td>Fish</td>
<td>Oncorhynchus mykiss¹</td>
<td>Central Valley steelhead DPS</td>
<td>FT, FX, CT</td>
</tr>
<tr>
<td>Fish</td>
<td>Pogonichthys macrolepidotus</td>
<td>Sacramento splittail</td>
<td>SSC</td>
</tr>
<tr>
<td>Fish</td>
<td>Spirinchus thaleichthys¹</td>
<td>Longfin smelt</td>
<td>FC, CT, SSC</td>
</tr>
<tr>
<td>Amphibians</td>
<td>Emys marmorata</td>
<td>Western pond turtle</td>
<td>SSC</td>
</tr>
<tr>
<td>Reptiles</td>
<td>Thamnophis gigas</td>
<td>Giant garter snake</td>
<td>FT, CT</td>
</tr>
<tr>
<td>Birds</td>
<td>Buteo swainsoni¹</td>
<td>Swainson’s hawk</td>
<td>CT</td>
</tr>
<tr>
<td>Birds</td>
<td>Elanus leucurus</td>
<td>White-tailed kite</td>
<td>FP</td>
</tr>
<tr>
<td>Birds</td>
<td>Laterallus jamaicensis cotemiculus¹</td>
<td>California black rail</td>
<td>CT, FP</td>
</tr>
<tr>
<td>Birds</td>
<td>Melospiza melodia</td>
<td>Song sparrow “Modesto” population</td>
<td>SSC</td>
</tr>
<tr>
<td>Mammals</td>
<td>Lasius russosevillii</td>
<td>Western red bat</td>
<td>SSC</td>
</tr>
</tbody>
</table>
Table 2  Potentially Occurring State and Federally Listed Species in the Columbia Cut Study Site Vicinity

<table>
<thead>
<tr>
<th>Notes: DPS = distinct population segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>¹Known to occur within the study site; ²Blooming Period: June-September; ³Blooming Period: May-September; ⁴Blooming Period: April-November;</td>
</tr>
<tr>
<td>⁵Blooming Period: May-August; ⁶Blooming Period: May-November</td>
</tr>
</tbody>
</table>

Status Notes:

U.S. Fish and Wildlife Service (USFWS):

FE = Endangered (legally protected)

FT = Listed as threatened under the federal Endangered Species Act

FC = Candidate for listing under the federal Endangered Species Act

FX = Critical Habitat

California Department of Fish and Wildlife (CDFW):

CE = Endangered (legally protected)

FP = Fully protected species—may not be taken or possessed without a permit from the Fish and Game Commission

SSC = California Species of Special Concern

CT = Threatened (legally protected)

California Native Plant Society:

CRPR 1B = Plant species considered rare or endangered in California and elsewhere (protected under the California Environmental Quality Act, but not legally protected under the Endangered Species Act or California Endangered Species Act)

CRPR 2 = Plant species considered rare or endangered in California but more common elsewhere (protected under the California Environmental Quality Act, but not legally protected under the Endangered Species Act or California Endangered Species Act)

Search Criteria: Database searches were conducted using the USFWS online database, CDFW’s California Natural Diversity Database (CNDDB), and California Native Plant Society’s (CNPS) Inventory of Rare and Endangered Plants of California to identify sensitive species that could occur in the study site. The database searches included the U.S. Geological Survey (USGS) 7.5-minute quadrangles for the study site (Bouldin Island and Terminous) and the surrounding seven quadrangles: Holt, Isleton, Lodi North, Lodi South, Stockton West, Thornton, and Woodward Island.

Table 3  Environmental Permits Potentially Required for the Columbia Cut Study Site

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Agency and Permit Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Federal</td>
<td>USACE 408 permission (if project would affect the McDonald Island levee, a USACE project levee), and USACE 404 Permit, Nationwide Permit (if area affected by dredge and fill activities is less than or equal to 0.5 acre of permanent impacts) or Individual Permit (if permanent impacts exceed 0.5 acre)</td>
</tr>
<tr>
<td></td>
<td>USACE Section 10 Rivers and Harbors Act authorization (if structures are a required component of project design)</td>
</tr>
<tr>
<td></td>
<td>Section 106 compliance with National Historic Preservation Act</td>
</tr>
<tr>
<td></td>
<td>Federal ESA compliance (if federal species and critical habitat are present within the study site); consultation with USFWS and NMFS required</td>
</tr>
<tr>
<td>State</td>
<td>RWQCB 401 water quality certification (CEQA compliance required)</td>
</tr>
<tr>
<td></td>
<td>RWQCB NPDES Construction General Permit (if ground disturbance is greater than 1 acre)</td>
</tr>
<tr>
<td></td>
<td>CDFW LSAA (CEQA compliance and CESA compliance required)</td>
</tr>
<tr>
<td></td>
<td>CSLC Lease (the project may be covered under existing MOU)</td>
</tr>
<tr>
<td></td>
<td>Central Valley Flood Protection Board Encroachment Permit</td>
</tr>
<tr>
<td></td>
<td>Delta Stewardship Council Consistency Determination</td>
</tr>
<tr>
<td>Regional and Local</td>
<td>Reclamation District No. 2030 and No. 2041 Encroachment Permits</td>
</tr>
<tr>
<td></td>
<td>San Joaquin County Grading Permit (unless the project is exempt)</td>
</tr>
</tbody>
</table>

Notes: CDFW = California Department of Fish and Wildlife; CEQA = California Environmental Quality Act; CESA = California Endangered Species Act; CSLC = California State Lands Commission; ESA = Endangered Species Act; LSAA = Lake or Streambed Alteration Agreement; MOU = Memorandum of Understanding; NMFS = National Marine Fisheries Service; NPDES = National Pollutant Discharge Elimination System; RWQCB = Regional Water Quality Control Board; USACE = U.S. Army Corps of Engineers; USFWS = U.S. Fish and Wildlife Service
Memo: Hydrodynamic Data Collection, Processing, Interpolation, and Analysis in San Joaquin River Junctions at the Head of Old River, Turner and Columbia Cuts in 2013 and 2014

Task Order No.: ESS-01

Author: Jon Burau and Paul Stumpner

Dated: October 23, 2014
# Table of Contents

1. INTRODUCTION ................................................................................................................... 1

1.1 Background .......................................................................................................................... 2

1.1.1 Overview of Hydrodynamics of the San Joaquin River in the Central and South Delta ................................................................. 2

1.1.2 San Joaquin River Junction at Old River ................................................................. 3

1.1.3 San Joaquin River Junctions at Turner and Columbia Cuts ............................ 3

1.2 Methods: General Approach .......................................................................................... 6

1.3 Critical Streakline: Introduction and Relevance ....................................................... 8

1.4 Critical Streakline: Computation ............................................................................. 10

1.4.1 Discharge Ratio ........................................................................................................ 10

1.5 Location, design and efficacy of behavioral barriers based on hydrodynamics .... 13

1.5.1 Barrier Angle .......................................................................................................... 15

1.5.2 Barrier Length ......................................................................................................... 16

1.5.3 Barrier Location ...................................................................................................... 17

1.5.4 Dispersive mixing – relaxation of fish spatial distributions - due to natural river hydraulics ................................................................. 17

1.5.5 Hydrodynamic conditions that recommend a behavioral barrier ........................ 19

1.5.6 Hydrodynamic conditions that do not recommend a behavioral barrier .......... 20

2. HYDRODYNAMIC ANALYSIS .......................................................................................... 21

2.1 CRITICAL STREAKLINE ESTIMATION .................................................................. 22

2.1.1 Head of Old River .................................................................................................. 22

2.1.2 San Joaquin River near Turner Cut - Pilot study ............................................. 24

2.1.3 San Joaquin River near Columbia Cut ............................................................ 25

2.1.4 San Joaquin River near Turner Cut – Full Study ............................................. 26

2.2 2D VELOCITY INTERPOLATION RESULTS ......................................................... 28

2.2.1 Head of Old River .................................................................................................. 29

2.2.2 San Joaquin River near Columbia Cut ............................................................. 30

2.2.3 San Joaquin River near Turner Cut – Full Study ............................................. 31

3. COMPARISON OF DELTA SIMULATION MODEL II WITH FIELD DATA ............ 33

3.1 Head of Old River .......................................................................................................... 33

3.2 San Joaquin River near Turner Cut ........................................................................... 34

4. SUMMARY AND RECOMMENDATIONS ....................................................................... 36

4.1 Summary of Analysis ................................................................................................. 40

4.2 Barrier Recommendations ......................................................................................... 43

4.3 Future Studies ............................................................................................................. 45

Experimental Operations ..................................................................................................... 45

4.3.1 Experimental Sequencing .................................................................................... 46
List of Figures

Figure 1. Map of the Sacramento/San Joaquin Delta with the locations of junctions studied for this report. Study locations are indicated by red circles. ........................................... 69

Figure 2. Time Series plot of (A) tidal (blue) and net (red) discharge at Turner Cut and (B) San Joaquin river discharge at Vernalis (green) and at net discharge Turner Cut (same as above, red) and export rate (black). .......................................................... 70

Figure 3. Time Series plot of (A) tidal (blue) and net (red) discharge at the San Joaquin River at Prisoners Point and (B) San Joaquin river discharge at Vernalis (green) and at net discharge Prisoners Point (same as above, red) and export rate (black). ....................... 71

Figure 4. Time series plot of (A) San Joaquin River discharge @ Vernalis (green), exports (black), and (B) the ratio of the net flow <Q> to <Q'> tidal range at Prisoner’s Point (red) and Turner Cut (blue). ................................................................. 72

Figure 5. Conceptual diagram of entrainment in a junction. Red regions denote the entrainment zone for the side channel whereas the green regions show the region where fish continue along the main channel. The red line between these regions is the critical streakline. Top panel shows the required conditions for fish to “go with the flow” – in this case the bulk discharge in each channel. These conditions include a uniform entrance fish spatial distribution AND behaviors that don’t result in fish crossing the critical streakline. In the bottom panel are indicated those conditions that create conditions where fish aren’t distributed in proportion to the flows in each channel. These conditions include a non-uniform entrance fish distribution as is shown and behaviors that cause fish to transit the critical streakline. ............................................. 73

Figure 6. Conceptual schematic showing conditions that are conducive to behavioral barriers (some of which are interdependent): (1) small ratios of side channel to main channel cross sectional areas (Asc/Amc << 1), (2) small and temporally stable discharge ratios (Qsc/Qmc << 1), (3) non-uniform spatial distributions, where Asc, Amc are the side channel and main channel cross sectional areas, respectively, and Qsc, Qmc are the side channel and main channel cross sectional discharges. If the up-current spatial distributions are biased toward the side channel (spatial distribution B) then entrainment in the junction is likely to be minimal in the absence of a barrier AND there would be very few fish for a behavioral barrier to move across the streakline to reduce entrainment. Therefore, because population level survival is the product of the entrainment rate (low in the case of a spatial distribution biased away from the side channel - B above) AND reach specific survival (which is low in the delta) the impact on population level survival of a behavioral barrier under these conditions is likely to be minimal and therefore not recommended. .................................................. 74

Figure 7. Bathymetry plot of Turner Cut, which suggests that the bypass flow in the San Joaquin is likely large relative to the flows in either North or South Turner Cuts. Based on channel capacity arguments, the North Turner Cut conveys most of the water into Turner Cut on flood tides and South Turner Cut conveys water on ebb tides as is indicated by the arrows. .................................................................................. 75

Figure 8. Bathymetry plot of Columbia Cut, which suggests that the bypass flow in the San Joaquin is likely large relative to the flows into Columbia Cut. Based on channel
capacity arguments, the South Columbia Cut conveys most of the water into Columbia Cut., as is indicated by the arrows................................................................. 76

Figure 9. Bathymetry plot of Head of Old River, which suggests that since the channel capacity in the mainstem San Joaquin River and Old River very near identical that the tidal timescale bypass flow in the San Joaquin is likely on the order of the flow in Old River at this junction................................................................. 77

Figure 10. The paths of taken by drifters (yellow lines) deployed during the 2011 BAFF™ experiment by the Department of Water Resources during converging flow conditions at the Georgiana Slough junction with the Sacramento River. (Data courtesy of Dave Huston, DWR). The critical streakline is shown as a red line. ...................... 78

Figure 11. The paths of taken by drifters (yellow lines) deployed during the 2011 BAFF™ experiment by the Department of Water Resources during downstream flow conditions (Data courtesy of Dave Huston, DWR). The critical streakline is shown as a red line. ................................................................. 79

Figure 12. Definition sketch defining the three flow conditions that occur in a tidally forced junction where the water is entering a side channel: (1) downstream flow in the main channel, (2) converging flow, and (3) upstream flow................................. 80

Figure 13. Definition sketch defining the three flow conditions that occur in a tidally forced junction where the water is exiting a side channel: (1) downstream flow in the main channel, (2) converging flow, and (3) upstream flow................................. 81

Figure 14. Schematic showing hydrodynamic conditions that suggest a behavioral barrier will not work: (A) the critical streakline is a significantly across the main channel from the side channel, (B) critical streakline is highly temporally variable (e.g. not stable), (C) the velocity distributions are converging into the side channel for a significant fraction of the tidal period, (D) the up-current fish spatial distribution is on the side opposite the side channel. We can’t evaluate condition (D) with the existing data but would need to deploy and evaluate 2D acoustic telemetry data to assess this condition. .................................................................................................... 82

Figure 15. Conceptual schematic of two barrier alignments and the relationship between the channel velocity and barrier orientation, where $U_a$ is the channel velocity, $U_e$ is the fish escape velocity, and $U_s$ is the sweeping velocity component along the face of the barrier (Turnpenny and O’Keeffe 2005).................................................................. 83

Figure 16 Conceptual schematic of the “relaxation” of the fish spatial distribution downstream of a behavioral barrier. This figure is completely conceptual since the research has not been done to verify the “relaxation” length scale, however, we know that, at some point, there exists a downstream distance where the fish spatial distribution is independent of the effects of the barrier. Shown is a fish entrance distribution that is biased to the side channel shore (label 1 above). As this distribution interacts with the barrier, it is biased to the bank opposite the side channel across the streakline (label 2), if the barrier is affective. However, once the fish move past the trailing edge of the barrier, this distribution begins to “relax” (Label 3). Lateral mixing due to natural river hydraulics such as surface boils, eddies off the trailing edge of the barrier and behavior likely all contribute to this relaxation. Therefore, behavioral barriers should not be placed to far upstream of the side channel entrance. .............................................. 84
Figure 17. Aerial view of Head of Old River showing location of SL-ADCP’s (HORe, HORs, and HORu), and parameters used for critical streakline calculations. The positive flow directions are indicated by white arrows. ................................................................. 85

Figure 18. Ariel view of San Joaquin River near Turner Cut (Pilot Study) showing location of discharge measurements (SJTC and TRN). Parameters used critical streakline calculations (Qu, Qs, Qd, Wu, and Wd). The positive flow directions are indicated by white arrows. ........................................................................................................ 86

Figure 19. Ariel view of San Joaquin River near Columbia Cut showing location of SL-ADCP’s (red dots and line) and locations of UL-ADCP’s (green dots). Each junction in the study area is labeled (J1, J2, and J3). Positive flow direction for each channel is indicated by yellow arrows. ........................................................................... 87

Figure 20. Aerial view of San Joaquin River near Turner Cut (Full Study) showing locations of SL-ADCP’s (red dots and lines) and UL-ADCP (green dot). Positive flow direction for each channel is indicated by white arrows. ........................................................................ 88

Figure 21. Time series data estimated using the velocity profile method for discharge calculation and integral method for discharge ratio and critical streakline calculation at HOR (a, top panel) tidally filtered discharge upstream (black), downstream (blue) and side channel (red) (b, middle panel) discharge ratio at upstream (black), downstream (blue) and total (red) and (c, bottom panel) critical streakline in distance from upstream left bank (black) and downstream left bank (blue). .................................................. 89

Figure 22. Upstream and downstream critical streakline positions at HOR. The solid line represents the mean critical streakline from the left and the dashed line represents one standard deviation from the mean.................................................................................. 90

Figure 23. Non-linear regression of the critical streakline from the left bank estimated from the discharge ratio and integral methods (a) at HORu; for positive flow conditions only and (b) at HORs; for negative flow conditions only........................................................................ 91

Figure 24. Timeseries data estimated using the index velocity method for discharge calculation and the discharge ratio method for discharge ratio and critical streakline calculation at SJTC (a) tidally filtered discharge upstream (black), downstream (blue) and side channel (red) (b) tidally filtered discharge ratio at upstream (black), downstream (blue) and total (red) and (c) tidally filtered critical streakline in distance from upstream left bank (black) and downstream left bank (blue). Note negative critical streakline indicate flow from side channel to main channel................................................................. 92

Figure 25. Time series data estimated using the velocity profile method for discharge calculation and integral method for discharge ratio and critical streakline calculation at SJCC (a) tidally filtered discharge upstream (black), downstream (blue) and side channel (red) (b) tidally filtered discharge ratio at upstream (black), downstream (blue) and total (red) and (c) tidally filtered critical streakline in distance from upstream left bank (black) and downstream left bank (blue). Note negative critical streakline indicate flow from side channel to main channel................................................................. 93

Figure 26. Upstream and downstream critical streakline positions at SJCC as reference from the left bank. The solid line represents the mean critical streakline and the dashed line represents one standard deviation from the mean........................................................................ 94

Figure 27. Non-linear regression of the critical streakline from the left bank at estimated from the discharge ratio and integral methods at CCuu; for positive flow. Note the
locations of the critical streakline using the integral method is discretized into bins equal to the measurement bin spacing (3.06 m) .......................................................... 95

Figure 28. Time series data estimated using the velocity profile method for discharge calculation and the integral method for discharge ratio and critical streakline calculations at SJTC (a) tidally filtered discharge upstream (black), downstream (blue) and side channel (red) (b) tidally filtered discharge ratio at upstream (black), downstream (blue) and total (red) and (c) tidally filtered critical streakline in distance from upstream left bank (black) and downstream left bank (blue). Note negative critical streakline indicate flow from side channel to main channel. .......................................................... 96

Figure 29. Upstream and downstream critical streakline positions at SJTC as reference from the left bank. The solid line represents the mean critical streakline and the dashed line represents one standard deviation from the mean. .......................................................................................... 97

Figure 30. Non-linear regression of the critical streakline from the left bank estimated from the discharge ratio and integral methods (a) at TCuu; for positive flow conditions only and (b) at TCddw; for negative flow conditions only. Note outliers outside of 2 standard deviations from the regression curve were removed. .......................................................... 98

Figure 31. Histogram plot of the difference in flow ratio (Qr) and particle ratio (Pr) for velocity interpolation algorithm at HOR for (a) all data (b) positive discharge conditions (c) negative discharge conditions. .......................................................................................... 99

Figure 32. Interpolated Velocity Vectors overlain on bathymetry plot at HOR for typical positive flow conditions. .......................................................................................... 100

Figure 33. Interpolated Velocity Vectors overlain on bathymetry plot at HOR for typical negative flow conditions. .......................................................................................... 101

Figure 34. Histogram plot of the difference in flow ratio (Qr) and particle ratio (Pr) for velocity interpolation algorithm at SJCC junction 1 for (a) all data (b) positive discharge conditions (c) negative discharge conditions. .......................................................................................... 102

Figure 35. Interpolated Velocity Vectors overlain on bathymetry plot at SJCC junction 1 for typical positive flow conditions. .......................................................................................... 103

Figure 36. Interpolated Velocity Vectors overlain on bathymetry plot at SJCC junction 1 for typical negative flow conditions. .......................................................................................... 104

Figure 37. Histogram plot of the difference in flow ratio (Qr) and particle ratio (Pr) for velocity interpolation algorithm at SJTC for (a) all data (b) positive discharge conditions (c) negative discharge conditions. .......................................................................................... 105

Figure 38. Interpolated Velocity Vectors overlain on bathymetry plot at SJTC for typical positive flow conditions. .......................................................................................... 106

Figure 39. Interpolated Velocity Vectors overlain on bathymetry plot at SJTC for typical negative flow conditions. .......................................................................................... 107

Figure 40. Tidally filtered discharge measured data (blue) and modeled data (black) at (a) HORu (b) HORs and (c) HORe. .......................................................................................... 108

Figure 41. Linear Regression of model discharge vs. measured discharge at HORu. Modeled data is phase corrected by +0.25 hours. .......................................................................................... 109

Figure 42. Linear Regression of model discharge vs. measured discharge at HORs. Modeled data is phase corrected by -0.25 hours. .......................................................................................... 110

Figure 43. Linear Regression of model discharge vs. measured discharge at HORe. Modeled data is phase corrected by -0.5 hours. .......................................................................................... 111
Figure 44. Histogram plots of amplitude errors between measured and modeled data. Data is separated based on tidal phase; top panels are during positive discharge and bottom panels are during negative discharge at (a,d) HORu (b,e) HORs and (c,f) HORe. Number in the top left corner indicate mean amplitude differences for that site and discharge range. ................................................................. 112

Figure 45. Time series data for SJTC (a) 15 min average discharge estimated from measured data (blue) and from model (black) (b) Tidally filtered discharge from measured data (blue) and model data (black). ........................................................................................................ 113

Figure 46. Histogram plots of amplitude errors between measured and modeled data at SJTC. Data is separated based on tidal phase (a) top panel is positive discharge values and (b) bottom panel is negative discharge values. ............................................... 114

Figure 47. Linear Regression of model discharge vs. measured discharge at SJTC. Modeled data is not phase corrected................................................................. 115

Figure 48 Comparison entrainment rates, $\psi$, and survival, $S$, between acoustically tagged juvenile salmon taking an Old River route through the central delta versus remaining in the mainstem San Joaquin based on 6-year study data collected in 2010 (Courtesy of Rebecca Buchanan). ................................................................. 116

Figure 49 Comparison entrainment rates, $\psi$, and survival, $S$, between acoustically tagged juvenile salmon taking an Old River route through the central delta versus remaining in the mainstem San Joaquin based on 6-year study data collected in 2011 (Courtesy of Rebecca Buchanan). ................................................................. 117

Figure 50. Ariel View of Columbia Cut and suggested placement of behavioral barriers. Option 1 would be placed where data was collected but may be at either too steep of an angle or be unnecessarily long. Option 2 presumably would have the same effect but be significantly small, and therefore more cost effective. White arrows indicate relative magnitude of flow and direction during positive flow conditions. The main stem San Joaquin flows are roughly four times the flow in the CCuu and the flow in Columbia Cut is about half of that. .......................................................................................................................... 118

Figure 51. Ariel View of Turner Cut and suggested placement of behavioural barriers yellow lines. The two Negative flow barriers are suggested instead of a barrier inside of TCddw, since most of the flow from TCddw enters TCds on the flood tide. White arrows indicate relative magnitude of flow on the main steam San Joaquin relative to Turner Cut. The double ended arrow in Turner Cut indicates that during the ebb tide there is both positive and negative flow at Turner Cut. The relevant sites are labeled as well. .......................................................................................................................... 119

Figure 52. Schematic of combining a technologies. An operable barrier that modulates the flow so that the streakline is in an optimal position for an upstream behavioral barrier. The ration of the discharges, $Q_{old}/Q_{sj}$, collected from a pair of SL-ADCP’s shown are used to control the gate position. ........................................................................................................ 120

Figure 53. SL-ADCP deployment schematic showing two SL-ADCP’s which can be used in combination with the permanent USGS flow station TRN(Q) above to understand the influence of high San Joaquin River inflows and exports on the hydrodynamics of the Turner Cut junction. ........................................................................................................ 121

Figure 54. SL-ADCP deployment schematic showing four SL-ADCP’s which can be used to understand the influence of high San Joaquin River inflows and exports on the hydrodynamics of the Columbia Cut junction. ........................................................................................................ 122
Figure 55. Location of USGS-maintained flow and water quality stations in the Sacramento/San Joaquin Delta. ........................................................................................................... 123

Figure A56. Linear regression of flow measured at MSD and flow measured at HORu..... 124
Figure A57. Linear regression of flow measured at SJD and flow measured at HORs ...... 125
Figure A58. Linear regression of flow measured at OH1 and flow measured at HORe...... 126
Figure A59. Linear regression of flow measured HORu using the gage regression (IVM) and
the velocity profile method (VPM). ................................................................. 127
Figure A60. Linear regression of flow measured at HORs using the gage regression (IVM)
and the velocity profile method (VPM). .......................................................... 128
Figure A61. Linear regression of flow measured HORe using the gage regression (IVM) and
the velocity profile method (VPM). ................................................................. 129
Figure A62. Linear Regression of index velocity measured at SJTC and measured cross-
sectional velocity. ............................................................................................ 130
Figure A63. Linear Regression of index velocity measured at CCdd and measured cross-
sectional velocity. ............................................................................................ 131
Figure A64. Linear Regression of index velocity measured at CCds and measured cross-
sectional velocity. ............................................................................................ 132
Figure A65. Linear Regression of index velocity measured at CCdu and measured cross-
sectional velocity. ............................................................................................ 133
Figure A66. Linear Regression of index velocity measured at CCe and measured cross-
sectional velocity. ............................................................................................. 134
Figure A67. Linear Regression of index velocity measured at CCud and measured cross-
sectional velocity. ............................................................................................. 135
Figure A68. Linear Regression of index velocity measured at CCus and measured cross-
sectional velocity. ............................................................................................. 136
Figure A69. Linear Regression of index velocity measured at CCuu and measured cross-
sectional velocity. ............................................................................................. 137
Figure A70. Linear regression of flow measured CCdd using the gage regression (IVM) and
the velocity profile method (VPM). Dashed red line indicates 1:1 correlation...... 138
Figure A71. Linear regression of flow measured CCdu using the gage regression (IVM) and
the velocity profile method (VPM). Dashed red line indicates 1:1 correlation...... 139
Figure A72. Linear regression of flow measured CCud using the gage regression (IVM) and
the velocity profile method (VPM). Dashed red line indicates 1:1 correlation...... 140
Figure A73. Linear regression of flow measured CCus using the gage regression (IVM) and
the velocity profile method (VPM). Dashed red line indicates 1:1 correlation...... 141
Figure A74. Linear regression of flow measured CCuu using the gage regression (IVM) and
the velocity profile method (VPM). Dashed red line indicates 1:1 correlation...... 142
Figure A75. Linear Regression of index velocity measured at TCdde and measured cross-
sectional velocity. ............................................................................................. 143
Figure A76. Linear Regression of index velocity measured at TCddw and measured cross-
sectional velocity. ............................................................................................. 144
Figure A77. Linear Regression of index velocity measured at TCds and measured cross-
sectional velocity. ............................................................................................. 145
Figure A78. Linear Regression of index velocity measured at TCus and measured cross-
sectional velocity. ............................................................................................. 146
Figure A79.  Linear Regression of index velocity measured at TCuu and measured cross-sectional velocity. .......................................................... 147

Figure A80.  Linear regression of discharge estimated TCdde using the velocity profile method (VPM) as a predictor of the index velocity method (VPM). Dashed red line indicates 1:1 correlation.......................................................... 148

Figure A81.  Linear regression of flow measured TCddw using the index velocity method (IVM) and the velocity profile method (VPM). .......................................................... 149

Figure A82.  Linear regression of flow measured TCds using the index velocity method (IVM) and the velocity profile method (VPM). .......................................................... 150

Figure A83.  Linear regression of flow measured TCus using the index velocity method (IVM) and the velocity profile method (VPM). .......................................................... 151

Figure A84.  Linear regression of flow measured TCuu using the index velocity method (IVM) and the velocity profile method (VPM). .......................................................... 152
Acknowledgements

The USGS, California Water Science Center collected the sideward-looking Acoustic Doppler Current Profiler (SL-ADCP) data, moving boat discharge measurements, and provided discharge and water level data in the junction region. The California Department of Water Resources (CA-DWR), North Central Region Office provided bathymetry, discharge and water level data at several of their long term sites. CA-DWR, Bay-Delta Office, provided model discharge output from DSM2. The authors are grateful for a number of helpful reviews of initial drafts of this report by DWR staff.
1. INTRODUCTION

This report describes hydrodynamic measurements and entrainment potential at three junctions on the San Joaquin River (SJR) (Figure 1) as a means of evaluating the feasibility of behavioral barriers to reduce entrainment of juvenile salmonids in these junctions into the central delta, where their survival is lower (Holbrook et al. 2009; 2013 Buchanan et al., 2013). Hydrodynamic data were collected at: (1) Head of Old River (HOR) in the summer of 2013 (equipment deployed for 113 days); (2) a pilot study at Turner Cut (SJTC) in the summer of 2013 (230 days); (3) Columbia Cut (SJCC) during the winter of 2013-2014 (78 days), and (4) a “full scale” study at SJTC and the summer of 2014 (69 days) (Figure 1). Whereas there are numerous factors involved in siting barriers at junctions to increase population level survival of juvenile salmon; factors such as the local geometry, habitat, and predation rates as well as the spatial and temporal distribution of juvenile salmon in the junction, to name a few, the recommendations in this report are based purely on hydrodynamic arguments using field data collected over a relatively narrow set of hydrologic conditions represented by mostly low San Joaquin River inflows. All of these junctions are strongly tidally influenced and thus a major objective of our experimental design was to capture the tidal timescale dynamics, which would, necessarily include measurements that capture spring/neap cycle variability, a well-known fortnightly period (14 day) oscillation in tidal energy (Conomos et al., 1979). To capture spring/neap cycle variability, it is necessary to measure several spring/neap cycles, a minimum of 2, the Nyquist frequency based on the fundamental Sampling Theorem (Hamming, 1983; Stearns and David, 1988). For these studies, we met this objective by collecting data for ~8 spring/neap cycles at HOR; ~16 cycles during the pilot SJTC and ~5 cycles during the full study at SJTC; and ~5 cycles at SJCC. Clearly, though,
these data collection periods are too short to capture seasonal and multi-year variability in the net flows in these junctions caused primarily by seasonal scale variability in the San Joaquin River inflows and export rates, which would involve multi-year deployments. Nevertheless, even though most of the data collected in this report were made during low San Joaquin River inflows, the conditions measured are appropriate for first cut barrier evaluations because: (1) Columbia and Turner Cuts are strongly tidally affected and thus are only weakly influenced by San Joaquin River inputs and exports, except during extremely high San Joaquin River flows (Figure 2, Figure 3, Figure 4) and (2) increased San Joaquin river flows decrease entrainment potential in these junctions by increasing the ebb tide (e.g. outgoing) or bypass flow relative to the flow entering either Columbia or Turner Cuts. Following the nomenclature used in fish screen evaluations (NMFS, 2008), we define the bypass flow as the amount of water flowing in the main channel past a side channel (Figure 5); in this case the water flowing in the San Joaquin River flowing past Turner, Columbia Cuts and Old River. Therefore, entrainment potential at all three junctions was measured in this study under worse case conditions for entrainment into the central delta (e.g. low flow, drought conditions; more on this later).

1.1 Background

1.1.1 Overview of Hydrodynamics of the San Joaquin River in the Central and South Delta

Very little has been written in the published literature on how San Joaquin River inflows and exports affect the exchange of water between the mainstem San Joaquin and the central delta. Yet this information is particularly relevant in formulating a general understanding of the mechanics of entrainment of juvenile salmonids into the central delta from the San Joaquin River. In this section, we use historical data to get at a “big picture” understanding of San
Joaquin River/central delta exchange and to justify the use of low San Joaquin River conditions as appropriate for behavioral barrier scoping exercises at Columbia and Turner Cuts.

1.1.2 San Joaquin River Junction at Old River

The hydrodynamics at the head of Old River are fundamentally different than at San Joaquin River junctions with either Turner or Columbia Cuts. Because Old River is roughly 20 San Joaquin river miles (32 km) upstream of Turner Cut, it is less tidally dominated and more strongly influenced by San Joaquin River inputs and exports than either Columbia or Turner Cuts. Because of Head of Old River is located at a greater distance from the Bay and the San Joaquin River has a smaller cross section at this junction, the San Joaquin River input can completely “push” reversing tidal conditions downstream of the head of Old River in response to large winter storms, thereby increasing the bypass flow in the San Joaquin relative to the flow into Old River, reducing the entrainment potential there.

1.1.3 San Joaquin River Junctions at Turner and Columbia Cuts

In contrast, the hydrodynamics of the junctions at Turner and Columbia Cuts are dominated by the tides (Figure 2, Figure 3, Figure 4) which allows us to reasonably use data collected during low San Joaquin River inflows to scope behavioral barrier efficacy under moderate/typical wintertime San Joaquin River inflows. To evaluate the influence of moderately high San Joaquin River wintertime inflows on junctions at Turner and Columbia Cuts we looked at historical data, within Turner Cut and on the San Joaquin River at Prisoner’s Point (Figure 3) during WY2011, the last time the San Joaquin River inflows were moderately high, at roughly 30,000 cfs. Prisoner’s Point is more strongly tidally forced than the San Joaquin River at Turner Cut and Columbia Cut,. However the general response at Turner and Columbia Cut is analogous to Prisoners Point during increased San Joaquin River inflows and exports.
The net flows, at Prisoners Point, show the influence of the San Joaquin River inflows and exports (Figure 3B). We discuss the response at Prisoners point to three events as indicated by the vertical lines. In March, 2011, vertical line (1), the San Joaquin River flows increased from 10k cfs to roughly 30k cfs and pumping was curtailed (Figure 3B). The effect at Prisoner’s Point, and by extension to the San Joaquin River at Turner and Columbia Cuts, is a rapid increase in the net flow out of the estuary (positive discharge), although this effect is still order of magnitudes less than the strength of the tides in this region (Figure 3A). The San Joaquin River inflows gradually decrease until around the 1st of July, where exports jump from near zero to 10k cfs with little effect on the net flows at Prisoners Point (red curve in Figure 3B).

Remarkably, between the beginning of June and the beginning of August, the San Joaquin River inflows and exports were virtually identical at 10k cfs with corresponding near zero net flows at Prisoners Point – the net flows at this location were in balance. Under these conditions, juvenile salmonids wouldn’t be getting any help out of the system from the San Joaquin River at this location. Interestingly, around the first of August, the San Joaquin inflows dropped from 10k cfs to 5k cfs, while exports remained constant at 10k cfs and the net flows at Prisoners Point switched from going toward the bay (positive) to being directed toward the south delta (negative). In other words, the net flows at Prisoners Point would be moving salmon outmigrants into the central/south delta under these conditions. In summary, the mainstem San Joaquin reacts more strongly to changes in San Joaquin River inputs than to exports, yet both influences are relatively weak compared to the tides.

In contrast, the relative influence of San Joaquin River inflows and exports are reversed on side channels to the San Joaquin, where exports have a greater influence at Columbia and Turner Cut, than do the San Joaquin River inputs, as can be seen in Figure 4. For example, the large increase
in discharge at Vernalis in late March, condition (1), does increase the flow of water at Turner Cut, but the influence in Turner Cut is much less than on the San Joaquin at Prisoner’s Point. Mechanistically, water from large San Joaquin River inflow events is largely moved through the delta by the mainstem, where the side channels convey water through the central delta out to the bay only during the time the inflows on the San Joaquin are increasing, \( \frac{\partial Q_{SJ}}{\partial t} > 0 \) as is typical of barotropic (water surface slope) flows; where \( Q_{SJ} \) is the discharge in the San Joaquin River at Vernalis, \( \partial \) is the partial derivative, and \( t \) is time, Once the Vernalis inflows stop increasing the flows into Turner Cut fall back to pre-peak levels even though the San Joaquin River inflows remain relatively high at 3k to 2.5k cfs for several weeks. The increase in exports, around the first of June, vertical line (2), immediately increases the net flows into the central delta through Turner Cut whereas the drop in San Joaquin River inflows at the end of July from 10k to 5k cfs (vertical line 3) has virtually no effect on the exchange of water into the Central delta from Turner Cut. We would expect a similar response in Columbia Cut.

In summary, the net flows in the mainstem San Joaquin River are more strongly influenced by changes in Vernalis flows whereas, net exchanges into the Central Delta from Turner and Columbia Cut are more strongly influenced by exports. This makes intuitive sense since exports create a barotropic pressure gradient between the mainstem San Joaquin River and the south delta export facilities. Whereas, increases in Vernalis flows, create a barotropic pressure gradient across the entire delta between the south delta and the bay, but, because the mainstem San Joaquin River has the larger conveyance capacity, it takes most of the load during high inflow events on the San Joaquin River compared to Turner and Columbia Cut. Importantly, because the water surface gradient during high San Joaquin River flows is between the south
delta and the bay, and specifically not between the San Joaquin and the export facilities, then there is not an increase flow toward the central delta through Columbia and Turner Cut.

To quantify the dominance of the tides on the net flows on the mainstem San Joaquin River and in Turner and Columbia Cuts, we plotted a time series of the net discharge \(<Q>\) divided by the tidal range, \(<Q'>\), at Prisoner’s Point and at Turner Cut. Figure 4B shows that, except during the high outflow event, the net flows are less than 5 percent of the tidal discharge range at Prisoner’s Point. Even during a 30k cfs Vernalis flow, the net flow at Prisoners point is less than 2% of the tidal discharge range. At Turner Cut, the influence of exports and changes in the Vernalis flows are greater than on the mainstem San Joaquin River. Still, at low export rates the net flows are less than 1%, during 10k cfs export rates less than 3% and on the order of 4% during the big increase in Vernalis flows from 10k to 30k cfs. Thus, we conclude, given the strength of the tides in this region, the data collected during low flow conditions are sufficient for barrier scoping exercises at Turner and Columbia Cuts.

1.2 Methods: General Approach

In this report, we focus purely on the analysis of water velocity patterns as a means determining (1) the suitability of behavioral barriers in junctions as a means of reducing entrainment in the central delta, and, if suitable, (2) the placement of behavioral barriers within a junction.

The analysis of water velocity patterns as a means of understanding juvenile salmon entrainment has been thoroughly studied in the Walnut Grove region (at the Delta Cross Channel and at Georgiana Slough) and is discussed in detail in Horn and Blake, 2003, Blake and Horn2006; DWR, 2012). In these reports, a conceptual framework is presented that characterizes juvenile salmon entrainment rates in junctions as the interaction between the up-current fish spatial
distribution and entrainment zones created by the velocity fields in the junction (Figure 5). For the purpose of discussion, entrainment in junctions occurs as a two-step process: (1) processes that occur upstream of the junction, within a Lagrangian frame of reference (e.g. moving with the mean advection), which create the fish entrance distributions in the junction, and (2) processes that occur within a junction, in an Eulerian frame (DWR, 2012 GSNPB report -in review, for a more detailed description). This separation is useful because the processes that govern each of these steps operate at different time and space scales (e.g. within different reference frames). For instance, fish entrance distributions in junctions typically are created at timescales that are much longer than the transit time in the junction and occur over varying distances upstream, depending on the interaction between the tidal forcing and river flows at any given time.

We focus on the junction hydrodynamics only in this report as an initial behavioral barrier scoping exercise – leaving the more difficult and experimentally expensive study of actual entrainment rates, which involve the interaction between the fish entrance distributions and hydrodynamics, for follow-up studies. As we discuss in this report, it is possible to assess the potential that a behavioral barrier will work at a given junction based on an analysis of the hydrodynamics alone. How well a behavioral barrier will work will depend on the temporal evolution of the up-current fish spatial distributions in combination with the velocity fields discussed here.

In general, hydrodynamic conditions favor behavioral barriers where the bypass flow is large relative to the flow into the side channel. Or, in terms of junction geometry, behavioral barriers can work if the main channel is much larger (e.g. has a greater channel capacity), than the side channel (Figure 6). These conditions are met for both Turner (Figure 7) and Columbia Cut
(Figure 8), whereas, these conditions are not generally met for Old River (Figure 9). In the next sections, we go beyond these general qualitative geometric observations, which are useful in initial scoping exercises, to develop/discuss quantitative metrics that have the specificity necessary to not only inform initial assessments of behavioral barrier efficacy but also provide the level of detail necessary to begin defining barrier location and design.

1.3 Critical Streakline: Introduction and Relevance

Evidence from past studies on juvenile Chinook salmon entrainment in Georgiana Slough suggest that instantaneous water velocity patterns in the immediate vicinity of the Georgiana Slough junction affect entrainment in Georgiana Slough (Horn and Blake, 2004, 2011 GSNPB report). While it would be ideal to directly measure water velocity patterns within junctions at high spatial and temporal resolution over the full range of conditions that outmigrating salmon are likely to encounter during the outmigration period, typically winter through spring, the costs associated with measuring a junction-scale velocity field on a continuous basis makes this impractical. Instead, side-looking Horizontal Acoustic Doppler Current Profilers (H-ADCPs) were used to make numerous velocity measurements in the junction areas, and a novel interpolation scheme was used to interpolate the surface water velocity fields in the junction at 15 minute intervals for a subset of the 2012 GSNPB study period (GSNPB - Appendix F). The goal of this exercise is to develop techniques to estimate the location of entrainment zones within tidally forced junctions without measuring the full 2D velocity field.

Particles (or drifters, or fish that are minimally behaving) that enter any junction are either transported into side channel or bypass it, as is shown in Figure 5. We can summarize our knowledge about the location of the entrainment zones shown in Figure 5 by defining the location in the river cross section where the two entrainment zones meet. We define the critical
streakline as the spatial divide between entrainment zones, expressed as the distance from the side of the river with the side channel, in this case the river left bank. This concept is illustrated in Figure 5, which shows the critical streakline as the location in the main channel that separates the entrainment zone for particles that enter the side channel (red) and the entrainment zone for particles that bypass it (green). This concept is documented in the field by the tracks of surface drifters released by DWR during the 2011 BAFF™ experiment; drifter tracks for downstream flow conditions are given in Figure 10, and for reversing conditions in Figure 11 which show drifter paths diverging in the region around the critical streakline.

The critical streakline concept is a way of collapsing a complex flow field into its essence with regard to fish fates, providing a simple metric for comparing the entrainment potential under a variety of conditions within a junction and between junctions. For example, at any instant in time, the critical streakline reduces the complexity of the entire flow field down to a single Lagrangian trajectory that can be represented simply by the distance from the shore, \( X_u \), to the trajectory’s location in the river cross section (Figure 5). The advantages and limitations of various techniques for computing the location of the critical streakline are discussed in detail in appendix F (DWR, GSNPB report), but in general, critical streakline calculations are most informative if detailed velocity measurements, drifter tracks, or fish entrainment data are used to verify the simplified calculations in appendix F.

As we will see, a behavioral barrier will work well if there are a large number of fish within a side channel entrainment zone that is narrow and temporally stable. In other words, a behavioral barrier will work well when there are a large number of fish within the side channel entrainment zone that can be moved a relatively short distance across the streakline to avoid entrainment (Figure 6). Still, for the purposes of this report we ignore the consequences of space and time
varying fish spatial distributions and leave this for a more detailed investigation that would include hydrodynamic monitoring AND multidimensional acoustic telemetry, an experiment that would be much more complicated and expensive than simply collecting hydrodynamic data alone.

1.4 Critical Streakline: Computation

In the absence of detailed, junction specific hydrodynamic data, the location of the critical streakline can be estimated using flow station discharge records to compute junction Discharge Ratios which then can then be scaled by the cross-sectional width of the river to produce critical streakline location estimates. Detailed analysis of critical streakline estimates produced using this approach suggests that, in the absence of detailed junction information, it is preferable to use the junction discharge ratios (see below) as a surrogate for entrainment zone location for statistical purposes, rather than scaling these ratios to produce low precision estimates of the critical streakline location (Appendix F in the GSNPB report). For this reason, discharge ratios, described below, provide a better general metric for understanding the effects of tidally forced velocity patterns on juvenile salmon entrainment in junctions because discharge ratios can be computed accurately for all junctions in the Delta using existing flow station data and are comparable between junctions.

1.4.1 Discharge Ratio

The streakline position is extremely useful because it can be used to quantify the degree to which physical processes contribute to entrainment by comparing streakline positions with observed tagged fish spatial distributions. However, streakline positions are site specific and depend on the local bathymetry, and, in the absence of detailed bathymetry and velocity data they collapse to the discharge ratio scaled by the width of the channel (Appendix F in the GSNPB report),
although this estimate will likely be biased towards the bank, which is why we measured the velocity and bathymetry profiles. Thus, if we define the discharge ratio $R_U$ as the proportion of the flow that enters the side channel from the main channel from upstream and $R_D$ as the proportion of the flow that enters the side channel from downstream (Appendix F), we have

$$X_u = W_u \left( \frac{Q_s}{Q_u} \right) = W_u R_u \quad (3.25)$$

and

$$X_d = -W_d \left( \frac{Q_s}{Q_d} \right) = W_d R_d \quad (3.26)$$

Where $X_u$, $X_d$ is the distance from river left of the streakline position when water is entering a side channel from upstream and downstream, respectively.

Many tidally forced junctions in the delta, including Columbia and Turner Cuts, experience a third set of velocity conditions where the flow converges into the side channel from both upstream and downstream. To account for these time periods, we define the discharge ratio under converging flow conditions as $R_C$, which is identically 1 (or 100%). Defining the discharge ratios in this way suggests a series of six states shown in Figure 12 and Figure 13 that represent all of the conditions that must be considered to correctly compute the discharge ratio in junctions where the tidal currents are reversing.

Since each of the states shown in Figure 12 and Figure 13 are mutually exclusive we define the total discharge ratio as

$$R_Q = R_U + R_C + R_D \quad (3.27)$$
which varies from zero to one and encompasses all possible flow conditions. Conceptually, $R_Q$ represents the fraction of the total flow entering the junction that enters the side channel of interest, and by extension, $R_Q$ provides a general idea of the size of the side channel’s entrainment zone relative to the junction. If $R_Q$ is close to 0, we know that the channel’s entrainment zone is small and entrainment probability is low. On the other hand, if $R_Q$ is close to 1 then we know that the channel’s entrainment zone covers most of the junction area and that entrainment probability will be near 100%. During times when $R_Q$ varies between these extremes the location of a side channel’s entrainment zone relative to the spatial distribution of fish in the junction will determine the overall entrainment probability.

By convention, the component R’s are all strictly positive for water entering a side channel (Figure 13), and negative for water exiting a side channel into the main channel (Figure 12). In this way, we account for conditions in which fish may be entrained in a side channel but returns when the flows reverse in the side channel into the main channel.

By maintaining all three of these variables separate from the total discharge ratio ($R_Q$) we can independently quantify how each of the conditions in Figure 12 and Figure 13 varies throughout the tidal cycle, which is important in understanding what types of fish guidance technologies may work in a given junction. In addition, the total discharge ratio will tell us how each of the flow conditions contribute to the tidally averaged discharge ratio under a variety of hydrologic conditions, especially when the flows from the side channel are reversing. The value of the discharge ratio can then be correlated with entrainment rates to quantify, in a simple way, the effect of flow patterns on entrainment rates.
The streakline concept and its non-dimensional counterpart the discharge ratio, $R_Q$, are conceptually useful because they focus our attention on only those hydrodynamic/behavioral interactions that are relevant to entrainment, greatly simplifying an extremely complex problem.

One of the seminal observation in this paper is that the only behaviors that lead to a change in fate within a junction are those that lead to a crossing of the critical streakline (Figure 5).

Behaviors that result in fish remaining within each entrainment zone do not ultimately change their fate. Therefore, the farther a fish is away from the critical streakline the more it is “committed” to one channel or the other and thus the greater the effort it would take for fish to change fates – or, the harder it will be for a behavioral barrier to change a fish’s fate.

In the absence of behavior within the junction, we can influence entrainment by either changing the streakline position ($X_u$), by changing the velocity distribution within the junction, or by changing the entrance fish distribution. Since changing the location of the critical streakline within the junction would require making massive physical changes to channel geometries in the junction area, altering fish entrance distributions is the most practical way to change entrainment in tidally forced junctions, which we discuss next. We first describe hydrodynamic conditions that suggest a behavioral barrier may or may not work, then we explore the hydrodynamic data at Head of Old River and in Columbia and Turner Cuts to see if these conditions are met.

1.5 Location, design and efficacy of behavioral barriers based on hydrodynamics

The critical streakline or discharge ratio is the principal metric we use in evaluating whether a behavioral barrier is likely to work in a given junction and its location. In order for a behavioral barrier to work, it must move fish from within the side channel entrainment zone across the critical streakline. Therefore, the barrier should extend from as near to the side channel bank as
is practical and extend into the main channel so that it extends beyond the streakline position. In general, then, a narrow and relatively stable entrainment zone is optimal for a behavioral guidance structure because the distance that fish have to be moved to cross the streakline, \(X_u\), is short and has a consistent position in space (Figure 6). Large and/or inconsistent side channel entrainment zones are undesirable because they require very long (and thus expensive) barriers (Figure 14) to maintain an escape velocity (see section 1.5.1) at the barrier that is less than the swimming capabilities of the fish. Therefore, Floating Fish Guidance Structure (FFGS) manufactured by Worthington Industries and/or so-called non-physical barriers, such as Bio Acoustic Fish Fence (BAFF™), which used sound, light and bubbles to deter fish, will require a long barrier to maintain an acceptable escape velocity when there are large and/or inconsistent side channel entrainment zones. Additionally, depending on the barrier type, a long/large barrier can adversely affect navigation, can increase the hydrodynamic forces on the barrier and large barriers are more likely to be damaged from floating debris that can occur during the outmigration season. For example, even though the BAFF™ is considered a non-physical barrier, it requires a structure in the water column that can limit vessel traffic (e.g. vessels with a deep draft) and is subject to damage from floating debris.

In short, temporal stability of a streakline position relatively close to the side channel shore is the most important metric for recommending a behavioral barrier. If the streakline position is relatively close to shore and stable, then the details of the hydrodynamics in the junction can further inform barrier design.

From a design perspective, the streakline position tells how far out into the main channel the barrier must extend from the side channel bank. Additional design considerations include: (1) the angle a barrier makes with flow direction, (2) barrier length, (3) along-main-channel barrier
location and (4) the potential relaxation of fish downstream of the barrier. We take these in turn in the next section.

1.5.1 Barrier Angle

Narrow side channel entrainment zones or high densities of fish near the streakline within the side channel entrainment zone is desirable because the angle of the barrier, $\alpha$ (Figure 6a) relative to the principal velocity direction (usually aligned with the prevailing bathymetry) must be small so that a typical salmon outmigrants has the ability to avoid the barrier given the strong tidal currents that can occur in these junctions.

The angle of the barrier, $\alpha$, must be small so that the component of the velocity normal to the barrier, the escape velocity, is less than the swimming performance of the typical salmon outmigrant (Figure 15b). And, the alignment of the barrier needs to minimize the hydrodynamic forces on the barrier (Ben Geske, personal communication).

Thus, the angle-to-flow of the river, $\alpha$, is a critical element of barrier design. The general principle of angled barrier design used in louver screen arrangements requires that water velocity meets the barrier at a small acute angle so that fish need only make a relatively small turn to be guided along the face of the barrier. This arrangement also ensures that fish require a relatively low sustained swimming speed to avoid passing through the barrier (Rainey 1985; Turnpenny and O’Keefe 2005).

The swimming direction requiring the lowest escape speed is at 90 degrees to the line of the barrier and thus the design of the barrier should ensure that this velocity component is kept below the maximum sustainable swimming speed of the fish over the range of river flows for
which the barrier is designed to work. Figure 15 shows the relevant velocity components for an angled fish barrier.

The main channel velocity is the approach velocity, denoted \( U_a \). The velocity perpendicular to the barrier face is the fish’s escape velocity, \( U_e \). For a barrier angle \( \alpha \), this is calculated as:

\[
U_e = U_a \sin \alpha
\]

The sweeping velocity, \( U_s \), is the component parallel to the barrier face. This is used to calculate the time taken for the fish to traverse the screen from any given point, when swimming at velocity \( U_e \). It is calculated as:

\[
U_s = U_a \cos \alpha
\]

Typical swimming performance of juvenile Chinook salmon was determined by Swanson, Young, and Cech (2004), who reported a sustained swimming speed of 3.4 body lengths per second (BL/s). It should be noted that use of sustained swimming speed provides a margin of safety, as fish can develop significantly higher prolonged and burst speeds for short periods (Beamish 1978).

### 1.5.2 Barrier Length

The length of the barrier is determined by a combination of (1) the distance the barrier must be out in the main channel to cross the streakline, (2) the barrier angle so that the escape velocity does not exceed the swimming performance requirements, (3) how close the barrier can be to the river bank. Physical conditions, such as obstructions and shallow depths may restrict how close a barrier may be placed near the river bank. Moreover, near-bank fish distributions determined
from acoustic telemetry data may suggest the barrier doesn’t have to extend completely to the bank.

### 1.5.3 Barrier Location

The barrier should be located sufficiently upstream of the junction so the streaklines haven’t started to bend into the junction increasing the escape velocity (Figure 15; option A) but not so far away that the fish spatial distributions immediately downstream of the barrier shift back towards the side channel (Figure 16).

For instance, the more the streaklines begin to bend the shallower the barrier angle must be relative to the prevailing channel orientation to maintain an acceptable barrier angle, \( \alpha \). The extreme case of a behavioral barrier angle that won’t work is the placement of a behavioral barrier within the junction (Figure 15; option C), where all of the streaklines are perpendicular (e.g. \( \alpha = 90 \) degrees) to the barrier.

### 1.5.4 Dispersive mixing – relaxation of fish spatial distributions - due to natural river hydraulics

We can make some generalizations regarding the potential relaxation of fish distributions due to physical mixing, but any statements about relaxation due to fish behavior would be pure speculation at this point. We can quantify the relaxation by equating it to complete cross-sectional mixing, caused primarily by large-scale horizontal turbulent structures (e.g. the surface boils in Figure 16, which at high flows can have horizontal length scales on the order of the depth – roughly 10 m). Cross-section mixing is due to turbulent dispersion and can be quantified by the transverse mixing coefficient \( E_t \) for natural stream with little curvature and little along channel change in bathymetry given by Fischer et al. 1979 as:
\[ E_t = 0.6 \, d \, u^* \]

Where \( d \) is the channel depth and \( u^* \) is the shear velocity due to bottom shear stress. For a barrier that extends about mid-channel the length of channel (\( L \)) required for complete cross-sectional mixing can then be described as:

\[ L = 0.3 \, \bar{u} \, W^2 / E_t \]

Where \( \bar{u} \) is the averaged cross-sectional velocity, and \( W \) is the channel width (Fischer et al. 1979). An example of this calculation is at Columbia Cut where a barrier that extends about half the width of the river is recommended (see section 4.2). The variables are \( d = 8 \) m, \( \bar{u} = 0.3 \) m/s and \( W = 140 \) m. The shear velocity was not measured, but typically these are an order of magnitude or less than the mean channel velocity: for this exercise we assume \( u^* = 0.1 \, \bar{u} \). Therefore \( L \) required before complete cross channel mixing would be \(~ 12 \) km. Importantly, this estimate of the distance to achieve complete cross-sectional mixing is much longer than the width of Columbia Cut (0.1 km), or the length of proposed barriers and a much greater distance than we would want to place the barrier upstream of the junction. We can also make a general statement about \( L \) over a wide range of variables. The calculation of \( L \) will be most sensitive to changes in the width to depth ratio (\( W/d \)) and \( u^* \). Decreasing \( W/d \) by an order of magnitude or increasing \( u^* \) by an order of magnitude will decrease \( L \) by an order of magnitude to \(~ 1.2 \) km.

This analysis is primarily valid for a riverine environment, where flow is uni-directional. In an estuarine environment \( L \) will decrease as the number of tidal cycles increases, due to physical mixing as a result of oscillatory flow. Therefore this analysis would only be valid for the length of a tidal cycle. Generally, on the San Joaquin River the tidal excursions on the order of 6.5 km’s (\(~ 4 \) mi) (based on typical peak tidal velocities measured at Prisoners Point of 45 cm/s). We can
then safely assume that placing a barrier upstream on the order of 100 m will yield minimal relaxation due to physical mixing, especially when flow divergence at a junction is typically on the order of 10’s of meters upstream of a junction. Nonetheless, a reasonable relatively short distance upstream of the junction would be preferable since the relaxation due to fish behavior and the enhanced physical mixing downstream of the barrier due to the barrier is not known.

In summary, the streakline suggests (1) how far the barrier should extend into the main channel and the velocity distribution defines: (2) the barrier angle (Figure 15) and (2) the length of the barrier, and (3) how close the barrier can be positioned in the main channel to the side channel entrance so as to avoid the up-current bending of the streaklines into the side channel) and how far the barrier can be from the side channel based on (4) some unknown combination of physical and behavioral processes downstream of the barrier that control fish distribution “relaxation”.

1.5.5 Hydrodynamic conditions that recommend a behavioral barrier

In general, a narrow and relatively stable entrainment zone is optimal for a behavioral guidance structure because the distance that fish have to be moved to cross the streakline is short and has a consistent position in space. Weaker main channel current speeds, up to a point, are also desirable because they can lead to more effective barriers because the barrier angle can be steeper or can have a smaller footprint which would lessen the impact on navigation/boating, reduce hydrodynamic stresses on the barrier and reduce maintenance issues associated with debris. When the tidal velocities fall well below a fish’s swimming performance, say around slack water periods, hydrodynamic interactions with a behavioral barrier alone will have a much weaker influence on keeping fish out of side channel entrainment zones.
1.5.6 Hydrodynamic conditions that do not recommend a behavioral barrier

If, for the river inflow/export conditions expected during the outmigration season, the critical streakline is: (a) significantly across the main channel from the side channel (Figure 14a), OR the standard deviation of the position is large (Figure 14b) OR the velocity distributions are converging into the side channel for a significant fraction of the tidal period (Figure 14c), then behavioral barriers are not recommended. In the case of (Figure 14a) and (Figure 14b) the behavioral barrier would be large, extending virtually across the entire main channel, depending, of course, on the fish entrance spatial distribution. Under these conditions a behavioral barrier would be expensive, a possible hazard to navigation/boating, subject to increased stresses on the barrier and at increased risk of damage from floating debris. In the case of (Figure 14c) converging flows, the complete cross section in the main channel from both upstream and downstream the side channel is engaged in supplying water to the side channel. Given that the mainstem San Joaquin River is much larger than either Turner or Columbia Cut, converging flow patterns were only measured < 1% of the time. Converging flow patterns do occur at the Head of Old River for about 17% of the conditions measured and at most of the upstream junctions in the north delta. A solid barrier that completely blocks the flow under converging conditions is the only solution to reducing entrainment in the side channel under these conditions, since the entire junction is supplying water and fish to the side channel.

We next discuss the hydrodynamic data we collected at Head of Old River and at Turner and Columbia Cuts, to see if the hydrodynamics meet the criteria to recommend a behavioral barrier at these locations. Of course, ultimately the efficacy of the barrier at reducing entrainment will also depend on the fish entrance distributions.
After a discussion of the data we will evaluate the temporal evolution of the streakline position at each of these junctions to determine the suitability of behavioral barriers for keeping salmon outmigrants on the San Joaquin and out of the central delta (Figure 6). It should be recognized, however, that additional studies will be needed to determine if juvenile salmon outmigrants are significantly utilizing the side channel entrainment zone (Figure 6b) by concurrently collecting hydrodynamic measurements and 2D acoustic telemetry data.

2. HYDRODYNAMIC ANALYSIS

Hydrodynamic data were collected primarily from side-looking acoustic Doppler current profilers (SL-ADCP’s) and also several up-looking ADCP’s. These data provide velocity data used for discharge estimation and two-dimensional (2D) interpolated velocity fields.

Supplementary data sets used for processing, interpolation and analyses are: (1) Bathymetry data collected at HOR on January 6, 2012, and at SJCC and SJTC in May of 2012. These data sets are available from the California Department of Water Resources (CA-DWR), (2) discharge and/or water level data from the following gage stations operated by CA-DWR: Old River at Head (OH1), San Joaquin River at Mossdale (MSD), San Joaquin River near Dos Reis (SJD), and San Joaquin Venice Island (VNI), (3) discharge and stage data from a gage station operated by USGS-CAWSC near SJTC: Tuner Cut near Holt, CA (TRN) and (4) modeled discharge data for each of these junctions from Delta Simulation Model II (DSM2).
2.1 CRITICAL STREAKLINE ESTIMATION

The critical streakline is estimated using two methods (Burau and Stumpner, 2013). The first method (discharge ratio) assumes rectangular cross-section, and no horizontal or vertical velocity variability. The second method (integral method) assumes a fully discretized natural channel with accurate bathymetry and velocity. This calculation is made using equations outlined in Appendix B of Burau and Stumpner (2013). The integral method is more accurate but requires more detailed information. A least square regression between the discharge ratio and integral methods will be presented for each junction. At junctions where longer term flow data exists, at gage station or where applicable model data exists, the discharge ratio method can be corrected using the regression curve to yield more accurate results.

2.1.1 Head of Old River

The critical streakline is estimated upstream and downstream of the HOR junction using the discharge ratio and integral methods. For the discharge ratio method the variables in the calculation are defined as follows (Figure 17): the discharge estimated at HORu is the upstream discharge \( Q_u \), the flow estimated at HORe is the downstream discharge \( Q_d \), the discharge estimated at HORs is the side channel discharge \( Q_s \), the width of the upstream cross-section \( W_u \) is estimated to be 93 m and the width of the downstream cross-section \( W_d \) is estimated to be 76 m. For the integral method additional parameters are needed: the cumulative sum of the discharge along the upstream \( Q_{c,u} \) and downstream \( Q_{c,d} \) cross-sections.

The tidally filtered time-series of discharge shows net positive discharge into Old River for the entire record (Figure 21a). The net discharge from the upstream location on the San Joaquin is positive and the net discharge from the downstream location is negative (Figure 21a). Water entrainment into Old River is high, about 60% of the water from the San Joaquin enters Old
River, at the net San Joaquin River inflow and export rate during the study period, according to the discharge ratio calculation (Figure 21b). Similarly, the critical streakline at both the upstream and downstream locations is positive into Old River (Figure 21c). These results show that entrainment into Old River from the San Joaquin occurs on both phases of the tide (flood and ebb), and on average about half of the water flowing down the SJR is entrained into Old River.

In terms of managing fish passage at this junction, in order to effectively deter fish entrainment into Old River, barriers would need to be placed at both the upstream and downstream locations. The mean critical streakline at the upstream location is 26.48 m (SD = 36.33 m) using the integral method and 22.35 m (SD = 35.00 m) using the discharge ratio method (Figure 22). The linear correlation between these two methods is good ($R^2 = 0.972$) but there is lots of spread and overall the integral method is biased towards the left bank (Figure 23a). This is a counterintuitive result and given the inaccurate results of the VPM for estimating discharge this is probably not the correct method for evaluating the critical streakline at this location.

The mean critical streakline at the downstream location is 66.32 m (SD = 10.82 m) using the integral method and 59.90 m (SD = 13.95 m) using the discharge ratio method (Figure 22). The discharge ratio method is biased towards the left bank. The non-linear relationship has a low correlation ($R^2 = 0.715$) and there is a lot of spread in the data (Figure 23b). Nonetheless these results show that the majority of water from downstream enters Old River. Given the poor correlation and variability in the streakline results (both upstream and downstream), using the streakline estimate for engineering purposes, such as barrier placement, is not recommended. Nevertheless, the temporal variability and general trends are valid and suggest that the Head of Old River is not an ideal place for solely a non-physical behavioral barrier, for the San Joaquin River inflows and export rates studied, because the streakline takes up the majority of the
channel AND significant flow enters Old River from both up and downstream. These conditions would imply moving the fish across half the river using barriers both upstream and downstream in the junction. At higher San Joaquin River inflows, say when the tidal flows are not reversing with the tides into Old River and the export rates are lower relative to the San Joaquin inputs, an upstream behavioral barrier may work.

2.1.2 San Joaquin River near Turner Cut - Pilot study

The discharge ratio and critical streakline are estimated upstream and downstream of the junction of the SJTC using the discharge ratio method. The variables in the calculation are defined as follows (Figure 18): the upstream discharge ($Q_u$) is based on the index velocity rating at SJTC, the side channel discharge ($Q_s$) is from the USGS gage station TRN, the downstream discharge is $Q_u + Q_s$, the width of the upstream cross-section ($W_u$) is estimated to be 240 m and the width of the downstream cross-section ($W_d$) is estimated to be 280 m.

The tidally filtered time-series of discharge shows that for most of the record the net discharge is into TC, and that net negative (into Turner Cur or toward the central delta) discharge is greater during low river discharge (Figure 24a). The mean total ratio of water entering TC is less than 0.10 (Figure 24b). From mid-March to end of June the net discharge into TC is close to zero and therefore the discharge ratio and critical streakline are low (Figure 24b,c). When the net discharge on the SJR (July-October) is reduced the net discharge into TC increases, and the discharge ratio and critical streakline increases. This increase is more pronounced at the downstream location due to greater negative discharges. Still the total discharge ratio is never exceeds 0.3, and the downstream critical streakline never exceeds 100m. This finding is consistent with the bathymetry data that shows deeper water depth on the northwest channel to TC can hold more discharge (Figure 29).
To put these results in the context of fish passage at this junction, the highest entrainment is likely to result from low river discharge and reversing discharge from downstream on the SJR. The critical streakline (upstream and downstream) show that entrainment of water into TC is likely to occur outside the dredged shipping channel on the SJR, which could simplify the placement of diversion barriers. Because the critical streaklines positions are low, or close to the left bank, Turner Cut is a good candidate for a non-physical behavioral barrier placed in the San Joaquin, perhaps both upstream and downstream of the junction.

2.1.3 San Joaquin River near Columbia Cut

The critical streakline is estimated upstream and downstream at SJCC (Figure 19) using the discharge ratio and integral methods. The discharge estimated at CCuu is the upstream discharge ($Q_u$), the downstream discharge ($Q_d$) is the combined estimated discharge from CCdd and CCe, the side channel discharge is the combined estimated discharge from CCus and CCds, the width of the upstream cross-section ($W_u$) is estimated to be 120 m and the width of the downstream cross-section ($W_d$) is estimated to be 110 m. For the integral method additional parameters are needed: the cumulative sum of the discharge along the upstream ($Q_{cu}$) and downstream ($Q_{cd}$) cross-sections.

The tidally filtered time-series of discharge at SJCC shows net positive discharge at both the upstream and downstream locations and net negative discharge into the side channel (Figure 25a). The tidally filtered upstream discharge ratio at the upstream location is variable around zero, but generally is below zero (Figure 25b). The tidally filtered downstream ratio is very close to zero, suggesting very little to no flow is entrained from the downstream location (Figure 25b). The mean total discharge ratio is just below zero (-0.02), suggesting that on a tidal timescale there is very little net entrainment into Columbia Cut. The critical streakline shows similar trends.
at both the upstream and downstream locations with the critical streakline never exceeding 10 m, less than 10 % of the channel width (Figure 25c).

The length of Columbia Cut is shorter than the average tidal excursion therefore entrainment on shorter timescales may be important. The length of Columbia Cut is \( \sim 2100 \text{ m} \) and on a strong ebb time that last \( \sim 6 \text{ hours} \) the average mean channel velocity is \( \sim 0.12 \text{ m/s} \). This equates to a distance of \( \sim 2500 \text{ m} \), which is longer than the length of the channel. It is likely that mixing at the junction of Middle River and Columbia Cut would result in some portion of water exiting Columbia Cut into the San Joaquin is different from water that enters.

The most effective barrier solution would therefore minimize entrainment on of the ebb tide into the upstream channel at Columbia Cut (CCus). On an ebb tide ~ 40% of the flow from CCuu enters Columbia Cut. The mean critical streakline is 51.4 m (SD = 23.0 m), using the integral method and 48.8 m (SD = 25.6 m) using the discharge ratio method (Figure 26). The critical streakline calculations are very close between the two methods, but the discharge ratio method biases the streakline towards the left bank. The non-linear relationship between the two methods is very good (\( R^2 = 0.96 \)) (Figure 27), and the water entrainment has been accurately characterized using the methodology presented for this junction.

2.1.4  San Joaquin River near Turner Cut – Full Study

The critical streakline is estimated upstream and downstream at SJTC (Figure 20) using the discharge ratio and integral methods. The discharge estimated at TCuu is the upstream discharge \( (Q_u) \), the downstream discharge \( (Q_d) \) is the combined estimated discharge from TCdde and TCddw, the side channel discharge is the combined estimated discharge from TCds and TCus, the width of the upstream cross-section \( (W_u) \) is estimated to be 240 m and the width of the
downstream cross-section \(W_d\) is estimated to be 280 m. For the integral method additional parameters are needed: the cumulative sum of the discharge along the upstream \(Qc_u\) and downstream \(Qc_d\) cross-sections.

The tidally filtered discharge at SJTC shows a net negative discharge at all three locations (upstream, downstream, and side channel) (Figure 28a). The upstream and downstream discharge ratios are very low, the average combined discharge ratio is 0.05 and never exceeds 0.1 (Figure 28b). Similarity, the critical streakline at the upstream and downstream locations is very close to the left bank (Figure 28c). During the start of the ebb tide a small fraction of flow enters Turner Cut from the San Joaquin, but for most of the ebb tide water is exiting TC into the SJR. During the flood tide is when most of the water is entrained into TC from the downstream location. Timeseries plot of the upstream (TCus) and downstream (TCds) side channels show that more water is conveyed through TCds on the flood tide. Once again this finding is consistent with the bathymetry data that shows deeper water in TCds than TCus (Figure 29).

In terms of fish passage and water entrainment at this junction, several barriers could be placed to divert fish from entrainment into TC. The most effective would be downstream of the downstream side channel (TCddw) to deter fish from entering that channel on the flood tide. The next most effective would be upstream of the upstream side channel (TCuu) to deter fish from entering on the ebb tide.

At the upstream location (TCuu) the mean critical streakline is 16.25 m (SD = 38.70 m) using the integral method and 13.59 m (SD = 38.36 m) using the discharge ratio method (Figure 29). The non-linear relationship between the two methods is good \(R^2 = 0.99\), with the discharge ratio showing significant bias towards the left bank at lower values (Figure 30a). At the downstream
location (TCddw) the mean critical streakline is 82.37 m (SD = 25.89 m) using the integral method and 89.17 m (SD = 22.43 m) using the discharge ratio method (Figure 29). The discharge ratio and integral methods for critical streakline show an interesting non-linear relationship (Figure 30b), but the majority of the flow from TCddw is conveyed down TCds on the flood tide. Therefore, a barrier would probably be most effective that diverted fish from the channel TCddw all together on the flood tide rather than having a barrier that diverted fish from TCds.

### 2.2 2D VELOCITY INTERPOLATION RESULTS

The results of the 2D velocity interpolation results are presented in this section. In past studies, associated with acoustic telemetry studies, interpolated velocity fields are needed to compare to the fish tracks (Stumpner 2013a). For this study, interpolated velocity fields are presented to: (1) document the water velocities at potential barrier locations (2) assess the feasibility of producing interpolated velocity fields at these locations, which are geometrically complex involving several channels and channel junctions, and (3) to determine where spatial data gaps exist.

The Appendix (Section A3) outlines the interpolation algorithm. The key metric for evaluating the performance of the algorithm is the difference between the flow ratio ($Q_r$) and particle pathline ratio ($P_r$). We assume that the distribution of particles in the interpolation is a good representation of the flow fields, because measurements to validate the interpolated velocity fields were not made. Typically, validation measurements would be either DL-ADCP transects taken within most of the domain or sets of drifters released periodically throughout a tidal cycle.
Since these junctions have not been previously studied and validation measurements were not taken, then it is likely that the velocity fields will have errors. Nonetheless, these results can provide insight into the general velocity features as part of a first cut barrier scoping exercise.

2.2.1 Head of Old River

At HOR, the interpolation algorithm was run for the entire domain and data record (Figure 17), except one data gap from 9/12- 9/19. The following parameters were used in the interpolation algorithm: grid spacing of 10m, weighting parameter of 2, and discharge estimation from the IVM. Interpolated fields for positive and negative flow conditions are solved with the same parameters.

For this study period, positive and negative flow conditions occur 55 % and 45 % of the time, respectively. Positive flow is defined as flow at the upstream location (HORe). The difference between the \( Q_r \) and \( P_r \) is less than 10 %, for 96 % of the time for both positive and negative flow conditions. The mean difference between \( Q_r \) and \( P_r \) is -5.8 % and -3.7 %, for positive and negative flow conditions, respectively (Figure 31).

There appear to be errors in the velocity field near the junction for both positive and negative flow conditions. For both positive and negative flow conditions the divergent flow near the junction of HOR is not well defined (Figure 32, Figure 33). For negative flow conditions the flow hooks around the junction and flows into Old River, but this sharp hook is not well defined (Figure 33). At HOR it was difficult to measure > 50 % of the cross-section at all three measurement locations, due to shallow water depth (3-4 m). We presume the interpolation errors have less to do with the lack of coverage with the SL-ADCP’s but more to do with the placement
of the SL-ADCP’s. Having a SL-ADCP placed right at the junction looking upstream would help to better define the flow divergence right at the junction.

2.2.2 San Joaquin River near Columbia Cut

At SJCC the velocity interpolation only encompasses the domain at junction 1 (Figure 19). From the critical streakline analysis it was shown that entrainment into Columbia Cut is primarily at this junction. The interpolated velocity field can only be made if there is complete data at each of the measurement locations at this junction (CCud, CCus, and CCuu). There are four time periods of data gaps (see Appendix A1, for exact dates). The following parameters are used in the interpolation: grid spacing of 10 m, weighting parameter of 4, and the discharge estimation from the IVM. Interpolated velocity fields for positive and negative flow conditions are solved with the same parameters.

For this study period, positive and negative flow conditions occur 50 % of the time. Positive flow is defined as flow greater than zero at the upstream location. The difference between \( Q_r \) and \( P_r \) is less than 20% for 75 % of the positive flow conditions and 84 % for negative flow conditions. The mean difference between \( Q_r \) and \( P_r \) is 12.7 % and 7.3 %, for positive and negative flow conditions, respectively (Figure 34).

The greatest errors in the interpolated velocity fields appear to where the flow diverges or converges at the junction. During positive flow conditions, when the flow diverges, there are velocity discontinuities at the point where the velocity vectors diverge into Columbia Cut (Figure 35). During negative flow conditions, when the flow converges, there are a few velocity vectors that are perpendicular to each other (Figure 36). The reason for these discrepancies could be due to the choice of weighting parameter in the interpolation. Since no quantitative comparisons were
made the weighting parameter was chosen that yielded the most accurate $Q_r$ and $P_r$ comparison. The velocity field could perhaps be better resolved with an instrument deployed at the point of convergence/divergence of flow. There were no quantitative comparison made, but qualitatively the velocity fields are well resolved.

2.2.3 San Joaquin River near Turner Cut – Full Study

The SJTC junction is complicated because of the size of the domain, and the multiple downstream and side channels, therefore generating interpolated velocity fields is complicated. Some of the assumptions in the interpolation algorithm may be invalid for this analysis. For instance, the distance between the upstream and downstream location is 850 meters, and our sampling average occurs over 900 seconds (15 minutes), therefore for a particle to travel this entire distance over the sampling period the water velocity would need to be 1 m/s. The average cross-sectional velocities were closer to 0.2 - 0.3 m/s, therefore our assumptions in the particle tracking algorithm would be considered invalid. We instrumented all of the channels in the domain, plus several mid-domain instruments to help with the velocity interpolation, for a total of nine instruments. Still there are probably some aspects of the velocity field that were not well resolved. The interpolation algorithm was only run for time periods when there was a complete record from all sites. Velocity interpolations were run from 6/19 – 7/29, aside from data gaps from 6/21 – 6/23 and 6/28 – 6/29 and 7/6 – 7/19. Given the difficulties stated above, we still feel the interpolated velocity fields give a good representation of the velocity fields at this junction for the purposes of and initial barrier siting exercise.

The following parameters are used in the interpolation: grid spacing of 20 m, weighting parameter of 4, and the discharge estimation from the IVM. Interpolated velocity fields for positive and negative flow conditions are solved with the same parameters. The velocity data
from TCduw was not used in the interpolation. There was a significant phase error with the other velocity profiles, and it could not be determined what the source of the error was, whether it was an instrument biasing or time shift error. For this study period the positive and negative flow occurs 52 % and 48 % of the time, respectively. Positive flow is defined as flow greater than zero at the upstream location. The difference between $Q_r$ and $P_r$ is less than 20% for 75 % of the positive flow conditions and 84 % for negative flow conditions. The mean difference between $Q_r$ and $P_r$ is 12.7 % and 7.3 %, for positive and negative flow conditions, respectively (Figure 37).

The velocity fields appear to be well resolved from a qualitative perspective, with a few exceptions. During positive and negative flow conditions at the upstream junction (TCus) it appear the velocity field is not well-resolved (Figure 38, Figure 39). Near the junction, the velocity vectors are not aligned with the river banks, which is what we would expect. From the streakline analysis, at the TCus junction, we know that the streakline is close to the left bank on both phases of the tide. The interpolated velocity field show the same results. At the downstream locations where the main stem SJ splits between TCdde and TCddw, the diverging flow does not appear to be well represented. This is a very shallow area, and it was not possible to measure velocities in this area. From the streakline analysis we know most of the exchange of water at the downstream junctions occurs between TCddw, therefore it is not critical that the flow divergence between TCdde and TCddw was well resolved.

Based on our results it would be recommended for future studies associated with acoustic telemetry, to focus on instrumenting the upstream and downstream junctions rather than attempting to resolve the velocity fields for the whole domain.
3. COMPARISON OF DELTA SIMULATION MODEL II WITH FIELD DATA

A quantitative comparison of the discharge estimation from measured data and the output from a one-dimensional numerical model - Delta Simulation Model II (DSM2) is compared. These comparisons are needed to assess efficacy of using DSM2 as a management tool for water entrainment in these junctions. DSM2 was developed as a tool to look at macro-scale processes (i.e. the whole delta), our efforts focus on micro-scale processes (i.e. junction scale) therefore it is possible that DSM2 results will not work as management tool at these locations. The following are used as comparison tools:

(1) Timeseries plots of instantaneous (15 min.) and tidally averaged data
(2) Linear regression of model vs. measured data
(3) Histogram plot of flood and ebb amplitude errors
(4) Cross-correlation to determine phase errors

Phase lag is determined to occur at the maximum cross-correlation value where a correlation value of one equals a perfect correlation. A positive phase lag indicates that the model lags behind the measured estimation and a negative phase lag indicates the measured estimation behind the model. Measured data is collected on 15 minute time intervals, whereas the modeled data is output on 60 minute time intervals. For phase and amplitude comparisons the modeled data was linearly interpolated onto 15 minute time intervals.

3.1 Head of Old River

The discharge estimation from the IVM is used for model comparison. The tidally filtered discharge time-series and linear regression plots show that the model does a reasonable job
predicting discharge at HORu and HORe (Figure 40a,c), except during higher river discharge where the model under predicts discharge at HORu. At HORs the model consistently over predicts discharge (Figure 40b). The model under predicts discharge at HORu, as the slope of the linear relationship is over one (Figure 41). There is more spread in the relationship at positive discharge. At HORs the slope of the linear relationship is closer to one but overall the model over predicts discharge (Figure 42). There is a lot of spread in the relationship at lower discharge conditions, but the relation becomes tighter at higher positive or negative discharges. HORe shows the worst relationship between the measured and model data (Figure 43). On average the model over predicts discharge, but there is a lot spread in the data, so a generalized statement is hard to make.

The trends for each tidal phase for the entire data record is shown in Figure 44. As can be seen by the distribution of the amplitude differences for each tidal phase. The mean phase and amplitude errors for positive and negative discharge values are summarized in Table 1. Overall, the model does a fair job of predicting discharge timing at HORu and HORs but amplitude differences are greater. At HORe the amplitude differences are less but timing errors are greater. These errors should be considered when using DSM2 to evaluate junction scale hydrodynamics. Despite these errors, DSM2 could produce similar results for characterizing entrainment into Old River on the tidal timescale.

3.2  San Joaquin River near Turner Cut

Discharge estimation from SJTC using the IVM is used for model comparison. During peak positive and negative discharge the model under predicts the measured discharge by a factor of two or three (Figure 45a). Tidally filtered discharge time-series show that overall discharge at SJTC is under predicted by the model, and much of the variations are dampened (Figure 45b).
The mean phase errors are zero (Table 1), but the mean amplitude errors are large for both phases of the tide (Figure 46). The statistical relationship using a linear model is good ($R^2 = 0.933$) and there is little spread in the data, but the slope of the linear relationship shows that the model under predicts discharge on average by almost a factor or two (Figure 47). At higher positive discharge values the relationship becomes non-linear and differences in discharge are almost a factor of three. The index velocity rating did not cover the full range of positive discharge values, the highest measured was $350 \text{ m}^3/\text{s}$ whereas the highest estimated was $790 \text{ m}^3/\text{s}$. Still even at lower positive discharge values the model under predicts discharge. For negative discharge values the model under predicts discharge on average by a factor of two (Figure 47). Given the large amplitude errors, overall the model does a poor job of predicting discharge at SJTC

**Table 1.** Phase and Amplitude Errors in Measured Discharge Estimations compared to Model Estimations at HOR and SJTC

<table>
<thead>
<tr>
<th></th>
<th>HORu</th>
<th>HORs</th>
<th>HORe</th>
<th>SJTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase lag (hrs.)$^1$</td>
<td>0.25</td>
<td>-0.25</td>
<td>-0.50</td>
<td>0.00</td>
</tr>
<tr>
<td>Cross-Correlation$^2$</td>
<td>0.957</td>
<td>0.952</td>
<td>0.950</td>
<td>0.966</td>
</tr>
<tr>
<td>Positive Discharge Mean Amplitude Difference (m$^3$/sec)$^3$</td>
<td>2.63</td>
<td>-9.27</td>
<td>2.13</td>
<td>134.93</td>
</tr>
<tr>
<td>Negative Discharge Mean Amplitude Difference (m$^3$/sec)$^4$</td>
<td>-12.10</td>
<td>-7.77</td>
<td>0.42</td>
<td>-125.73</td>
</tr>
</tbody>
</table>

$^1$ Positive Phase lag indicates model lags behind measured estimation

$^2$ Cross-correlation value where phase lag occurs

$^3$ Positive Amplitude Difference indicates model has lower positive value than measured estimation

$^4$ Positive Amplitude Difference indicates model has lower negative value than measured estimation
4. SUMMARY AND RECOMMENDATIONS

Behavioral barriers have been suggested as one of the tools that we can use to increase population level survival of outmigrating juvenile salmonids throughout the delta (2009 NMFS Biological Opinion RPA IV.1.3, DWR, 2012 GSNPB report -in review). The basic idea is to encourage juvenile salmonids into routes with greater survival or away from those with lower survival by using a behavioral barrier which is designed to minimally effect the flow of water; water that then can be used to meet water quality, export objectives, increasing delta outflow, etc. For behavioral barriers to be useful, however, there needs to be a difference in the contribution a given route has on the total population level survival (e.g. to Chipps Island) versus other routes. The effect on the population level survival of any given route is not simply the survival in that route but rather the product of the survival in that route and the route entrainment probability. Thus, the survival in a given route is not the only variable to consider when evaluating whether a junction should employ a behavioral barrier to increase the population level survival. For example, the survival in a given route may be very low, yet if few fish use that route, the impact of that route on population level survival may be low and the effort associated with installing and maintaining a behavioral barrier may not be worth the cost. Thus, the product of the number of fish that use a given route and their survival in that route is the metric that should be used to assess the extent to which a behavioral barrier will contribute to population level survival. Since behavioral barriers are designed to minimally change the flow of water, their impact is aimed primarily at changing the route entrainment probability at a junction, presumably sending more fish down a higher survival route. Thus, in order for a behavioral barrier to increase population level survival there (1) needs to be a high percentage of fish that
use the lower survival route in the absence of a behavioral barrier and (2) there needs to be a higher survival route to divert fish into.

Based on the recent work of (Buchanan et al., 2013a, Buchanan et al., 2013b, Buchanan, et al., in prep.), we can see that survival of juvenile salmon emigrating from the San Joaquin River has been appallingly low in recent years: 5% in 2010 (Figure 48) and 2% in 2011 (Figure 49). This work clearly suggests that there is little difference in population level survival for juvenile salmon between the central delta (through the Old River route) and the mainstem San Joaquin. Thus, a behavioral barrier at Old River will have little to no effect on population level survival, even if it is one hundred percent effective at diverting fish away from the central delta and into the mainstem San Joaquin. In this case, a behavioral barrier will change where salmon die, but die they will, with virtually no difference in the total mortality rate through the delta.

In fact, based on these data, survival is greater for juvenile salmon that take the Old River route in both years (in 2010: $S_{OR}=0.07 > S_{SJ}=0.04$; and in 2011: $S_{OR}=0.04 > S_{SJ}=0.01$), most of this increase in survival is apparently due to taking a truck ride from the facilities to the central delta (e.g. salvage) (Buchanan, et al., in prep.). These data suggest that we should increase entrainment into Old River over the mainstem San Joaquin to increase survival of juvenile salmon emigrating from the San Joaquin!

Unfortunately, we don’t know the fish entrainment rates in Columbia and Turner Cuts with any level of precision because of the low sample size used in studies aimed at this question (DWR, 2014) nor do we have an assessment of the difference in the survival rates between the Turner and Columbia Cut routes versus the mainstem San Joaquin downstream of Columbia Cut.
In addition, the sample sizes in these studies shown in Figure 48 and Figure 49 are pretty low (1022 released in 2010 and 931 released in 2011, over seven releases under different hydrologic conditions) and the historical acoustic telemetry networks were not specifically designed to determine the influence of juvenile salmon taking routes associated with Turner and Columbia Cuts on the total population. Greater sample sizes could be used in future studies and the telemetry network could be changed in the future to assess the influence on population level survival of fish that take Turner and Columbia Cut routes.

Before significant effort is put into designing and constructing behavioral barriers at Turner and Columbia Cuts we must first determine: (1) what the route entrainment probability into these channels is in the absence of a behavioral barrier, and (2) if keeping fish in the mainstem provides a significant improvement in survival over those that enter the central delta through these junctions. If (1) route entrainment probability in either if these Cuts is low, then barriers will not appreciably increase population level survival and (2) if the survival in the mainstem San Joaquin is similar to juvenile salmon taking either Columbia or Turner Cuts, then changing the route entrainment probability in either of these junctions will not change population level survival. Finally, it would be useful to determine what percentage of juvenile salmon that take a “left turn” into Columbia and Turner Cuts: (1) use routes that lead to the pumps or (2) use routes that lead through the central delta toward the bay and how use of these central delta routes are influenced by San Joaquin River flows and export rates.

It is recommended that we understand the contradictory data (e.g. Figure 48 and Figure 49), and perhaps, before significant work occurs on these barriers, we study these junctions to address survival and entrainment rates of fish using these junctions. This would involve a slight modification of the existing 6-year study telemetry network and using a greater sample size.
To be absolutely clear, the data shown in Figure 48 and Figure 49 challenges the long held notion/assumption that survival is significantly less in the central delta than on the mainstem San Joaquin River (2009 NMFS Biological Opinion RPA IV.1.3). Barriers of any kind will not improve the population level survival of juvenile salmon if the assumption that central delta survival is lower than the mainstem San Joaquin is not true.

In short, designing and building multi-million dollar behavioral barriers based on the information we currently have is not recommended.

More generally, however, behavioral barriers are likely to be an effective option in increasing population level survival, if survival on the mainstem San Joaquin were increased through the creation of habitat (e.g. setback levees) and a modification of known predation hot spots, such as the straightening of sharp bends in the river, etc. Unless there is significant improvement of survival in the mainstem San Joaquin versus the central delta pathways, behavioral barriers may not increase population level survival.

The focus of this report, however, is not on whether a change in entrainment rate at Turner, Columbia Cuts and Old River is relevant to population level survival, instead this report is focused on whether behavioral barriers in Turner and Columbia Cuts and at Old River are likely to reduce entrainment of juvenile salmonids into the central delta.

Accordingly, in this report, we discussed a conceptual framework that allows us to evaluate the efficacy of behavioral barriers based on hydrodynamic principles: the entrainment zone and critical streakline. We show that, in the final analysis, the design of behavioral barriers should focus on moving fish out of side channel entrainment zones, across the critical streakline and into the main channel where they will bypass the side channel altogether, thereby avoiding
entainment into low survival pathways. We then discuss a general framework for spatial and temporal variability in streakline position that favor behavioral barriers and those that do not.

In general, hydrodynamic conditions favor behavioral barriers where the bypass flow is large relative to the flow into the side channel. Likely sites for behavioral barriers can easily be determined by looking at junction bathymetry as a first cut. Overall, a narrow and relatively stable entrainment zone is optimal for a behavioral guidance structures because the distance that fish have to be moved to cross the critical streakline is short and has a consistent position in space. From a design perspective, the critical streakline position determines how far a behavioral barrier would need to extend into the main channel from the side channel bank. A combination of fish swimming performance and the maximum velocity under stable streakline conditions determines the angle of the barrier to the main flow and how long the barrier must be. Finally, it is recommended that the along-channel position of the barrier in the main channel relative to the side channel be placed far enough up-current to avoid the bending of the streaklines into the side channel, but not so far up-current that the fish spatial distribution “relaxes” back across the critical streakline toward the side channel. We use the conceptual rubric summarized above to make recommendations based on a detailed examination of the hydrodynamic data collected at San Joaquin River junctions at Columbia and Turner Cut and at the Head of Old River. The details of how the data were collected, how calibrations were made, discussions of data quality, etc, are covered in the appendices.

4.1 Summary of Analysis

At HOR, three SL-ADCP’s provided data to evaluate junction scale hydrodynamics with 2D velocity and discharge metrics over a four month period in the summer of 2013. The range of velocities measured were 0 – 0.65 m/s (0 – 2.13 ft/s) and the range of discharges measured were
Two different methods, IVM and VPM, of discharge estimation from field data were compared and the results were encouraging. Based on mass balance metrics the results between methods are comparable. Linear regressions show non-linear patterns during reverse discharge conditions at HORu and HORe. These discrepancies are likely because the SL-ADCP’s could only profile < 50 % of the cross-section width. Critical streakline and discharge ratio metrics at HOR show that on average about one-half of the water that flows down the SJR is entrained into Old River, which is consistent with the entrainment rate data for 2010 and 2011 reported by Buchanan et.al. in press, (Figure 48 and Figure 49). During lower discharge conditions (roughly < 30 m$^3$/s or 1060 ft$^3$/s) more water is transported into Old River during the flood tide, but as the river discharge increases so too does the portion of water entering on the ebb tide. DSM2 modeled output shows good agreement with all sites at HOR in terms of amplitude and phase errors and linear regressions. DSM2 could be expected to show similar results with regards to entrainment at this junction.

For the SJTC pilot study, one SL-ADCP was used as an index velocity meter to estimate discharge with the IVM, over a seven and one-half month period in the spring and summer of 2013. These data and data from TRN were used to evaluate junction hydrodynamics using discharge metrics. Overall entrainment potential into TC is relatively low. When river discharge is lower and the net discharge into TC is reversed, entrainment potential increases. DSM2 modeled output show very large amplitude errors, as much by a factor of two or three, on both tidal phases. Because of this we conclude that DSM2 results should not be used to evaluate entrainment into TC.

At SJCC five SL-ADCP’s and two UL-ADCP’s provided near surface velocity measurements and discharge estimates using the IVM and VPM methods for about two months in the winter of
2013-2014. The range of velocities measured were 0 - 0.33 m/s (0 – 1.08 ft/s) and the range of discharges measured were -248 – 236 m³/s (-8750 – 8313 ft³/s). The mass balance errors using the VPM were a bit higher than the IVM, but the correlations between the IVM and VPM were quite good at all five SL-ADCP sites. Our results show that net flow into Columbia Cut is very small, but considering the length of Columbia Cut is short, a barrier to divert fish into the San Joaquin on the ebb tide could be effective. Just less than half of the water that is conveyed down the San Joaquin River side channel enters Columbia Cut on the ebb tide. Therefore, the barrier would need to extend about half the width of the river to be effective, but large vessels do not use this channel, so this configuration is physically doable.

At SJTC eight SL-ADCP’s and one UL-ADCP provided near surface velocity measurements and discharge estimation using the IVM and VPM methods for about two months in the summer of 2014. The range of velocities measured were 0 - 0.41 m/s (0 – 1.34 ft/s) and the range of discharges measured were -555 – 574 m³/s (-19609 – 20,279 ft³/s). The VPM over estimated discharge at several sites, but these sites were side channels sites where only about 10 % of the flow was conveyed, therefore there errors in these channels were not detrimental to evaluating junction scale hydrodynamics. The results for this study cover a lower range of San Joaquin River inflow conditions than the pilot study. The net discharge was negative during the period studied and the majority of water entrainment into SJTC occurred on the flood tide. The downstream side channel TCddw conveys the majority of water into Turner Cut, therefore diverting fish from this channel using a non-physical behavioral barrier could be an effective solution. A secondary barrier could be placed upstream of the upstream side channel (TCuu) to divert fish on the ebb tide.
Given the net flow in Turner Cut is roughly one order of magnitude lower than flow on the main stem San Joaquin the critical streakline will be relatively stable in space. Thus, the only way this level of streakline movement would significantly entrain more salmon outmigrants is if there is, on average, a large concentration of outmigrants in this region.

4.2 Barrier Recommendations

Streakline positions based on bulk flows are useful for the statistical purposes of understanding entrainment in mark recapture models (Holbrook et.al. 2009; 2013, Perry et.al., 2010; 2012; 2013) and as a first level behavioral barrier scoping exercise. However, for exact barrier placement, calculating the critical streakline based on the complete velocity field, or at least on a SL-ADCP in combination with the detailed cross sectional bathymetry, is needed.

Based on the methods defined in Section 1.5 and analysis of hydrodynamic data alone, we recommend further scoping of behavioral barriers at Turner and Columbia Cut and not at Head of Old River. We are currently evaluating the data collected during the 2008 and 2009 BAFF experiments at the Head of Old River (Buchanan et.al., 2011; and Bowen and Bark, 2010), to see if our conclusions are consistent with these data, but this analysis is beyond the scope of this report. The criteria we defined for an effective behavior barrier based on hydrodynamics are (1) The small critical streakline is close to the river bank so as to not interfere with channel navigation, and the deviation from the mean is small, (2) the angle at which the barrier is placed relative to the water velocity is small (Table 2) and the length of the barrier to achieve this angle is low, and (3) the time spent under converging flow conditions is negligible.

<p>| Design Angle Parameters for a Barrier Capable of Deflecting Juvenile Chinook Salmon |
|-----------------------------------------|-----------------|
| Attribute                               | Value           |
| | |</p>
<table>
<thead>
<tr>
<th>Fish Criteria</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum size of fish</td>
<td>60 mm</td>
</tr>
<tr>
<td>Sustained swimming speed</td>
<td>3.4 BL/s</td>
</tr>
<tr>
<td>Swimming speed (prolonged)</td>
<td>0.204 m/s</td>
</tr>
<tr>
<td>Maximum design channel velocity</td>
<td>0.5 m/s</td>
</tr>
<tr>
<td>Required barrier angle</td>
<td>24 degrees</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Velocity Type</th>
<th>SIN</th>
<th>COS</th>
<th>Angle</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Escape velocity</td>
<td>24</td>
<td>0.41</td>
<td>0.203</td>
<td>m/s</td>
</tr>
<tr>
<td>Sweeping velocity</td>
<td>24</td>
<td>0.91</td>
<td>0.457</td>
<td>m/s</td>
</tr>
</tbody>
</table>

Table 2 – Example calculation used to compute a design barrier angle, based on the fish size, sustained swimming speed (Courtesy of Getske, DWR).

For SJCC junction all these criteria are met. Figure 50 illustrates the placement of a behavioral barrier to route fish away from Columbia Cut on the ebb tide. From the streakline analysis the best position for the barrier at CCuu would be over half the width of the channel (Figure 26) and therefore have a higher than practical angle relative to the water velocity or be an extremely long barrier. Therefore a behavioral barrier outside on the main stem San Joaquin (Figure 50; Option 2) could be a more cost effective measure. Data was not collected at this location, but an estimation of discharge for the time period of data collection could be made from existing gage station data.

For the SJTC junction all the criteria are also met. Figure 48 illustrates the placement of behavioral barriers at upstream and downstream locations to minimize entrainment into TC on both phases of the tide (ebb and flood). At the upstream location (Figure 51; positive flow barrier) the barrier would have minimal impact on navigation and would be a small angle and relatively short. From the streakline analysis the downstream location in TCddw would need to encompass the entire channel in order to be effective; this would result in either a large angle...
with respect to the water velocity direction or a long barrier. Therefore our suggestion is to place two barriers on the mainstem San Joaquin in order to route fish away from TCddw and TCus.

At HOR all three criteria are not met, therefore a behavioral barrier alone is not recommended. Both the upstream and downstream critical streaklines are far from the river banks with a large deviation from the mean (Figure 22), therefore the barrier would need to have a large angle or be extremely long. Additionally, about 20% of the flow observations result in converging flow. In the next section we make recommendations for a future study where a combination of a behavioral barrier and operable gate could be implemented.

4.3 Future Studies

Experimental Operations
The period from January 1, 2011 through January 1, 2012 was a remarkable period for understanding how the south/central delta works from a transport perspective. Exports and the San Joaquin River inputs, when changed, were held steady for greater than month long periods and were changed independently and dramatically in a step function fashion – an experimentalist’s dream, because it allowed us to understand the effects of changes of a variety of factors and how they interact. An experimentalist trying to understand the south/central delta and how exports and San Joaquin River inflows affect entrainment of salmonids into the central delta from the mainstem San Joaquin River could not have asked for a better operational regime. Unfortunately, a limited number of flow stations were operational at this time and south/central delta flow conditions could only be inferred from the data on hand. Historically, exports are most often changed simultaneously with changes in San Joaquin inflows, and other factors, to maximize water supplies, which is understandable. Nevertheless, when changes in various
factors are made nearly simultaneously, it is virtually impossible to disentangle their individual contributions and how these factors interact. Given the delta is much more completely instrumented now, a great deal could be learned regarding fundamental system response, as was discussed in section 1.1.3, if the water project operators were working with scientists on experimental operations. Experimental operations similar to January 1, 2011 through January 1, 2012 coupled with the instrument configurations given in Figure 53 and Figure 54, and an additional few acoustic telemetry receivers to the USBR-funded 6-year study, would allow a detailed understanding of the effects of San Joaquin River inflows and exports on the hydrodynamics of entrainment of juvenile salmon at Turner and Columbia Cut, as well as Middle River (Figure 1). Whereas in this report, we were only able to infer what happens on the San Joaquin in the central delta generally, by examining the discharge ratio and streakline positions with instrumentation shown in Figure 55.

4.3.1 Experimental Sequencing

The conceptual framework of the entrainment zone suggests a multistep process for evaluating the efficacy of potential behavioral barriers based on level of effort and expense. Starting with inexpensive scoping steps first:

(1) Evaluate the bathymetry – a large difference in cross sectional area between the main channel (wide and deep) and side channel (narrow and shallow) suggests a behavioral barrier could be effective, at least from a hydrodynamic perspective.

(2) Conduct hydrodynamic experiments to evaluate streakline positions and how they vary with hydrologic conditions (e.g. San Joaquin River flows and exports).
(3) Conduct combined hydrodynamic and multi-dimensional acoustic telemetry experiments - for those junctions that pass steps (1) and (2) make sure: (a) the up-current fish distributions are not on the side opposite the side channel (Figure 6b) and warrant a behavioral barrier in the first place, (b) there are significant numbers of fish within the side channel entrainment zone (Figure 6a). It may well turn out that the side channel entrainment zone is narrow and stable but relatively few fish are in this zone and thus entrainment in this junction is low overall. Even if reach specific survival is low (i.e. within the central delta), a junction that may be well suited for a behavioral barrier base both on hydrodynamics and fish distributions may not be significant to population level survival if survival in each of the routes in a junction are similar and thus remedial actions elsewhere may be a better investment in increasing overall population level survival.

(4) Study actual barrier efficacy - place an operable barrier, which has the ability to be moved into the channel across the critical streakline and back to the near bank region (Similar to GSNPB 2014), in the context of a hydrodynamic/acoustic telemetry study as is shown for Turner and Columbia Cut (Figure 50 and Figure 51).

(5) Study “relaxation” due to physical mixing and fish behavior - a “relaxation” study could be combined with a concurrent acoustic telemetry study. Ideally, this experiment would take place over a stretch of river that is straight with small W/d and a high degree of mixing (i.e. large $u^*$) in order to minimize the distance required for full channel mixing and hopefully the equipment required to measure relaxation. Accurately quantifying the “relaxation” would also require a 2D acoustic telemetry array to extend at a minimum several 100 meters downstream, and an SL-ADCP recording in high frequency mode (1
ping per second or less) to resolve \( u^* \). We could then determine what the distribution would be due to physical mixing and combine this with the fish distribution data to potentially partition how much relaxation is due to physical mixing and how much is due to fish behavior.

4.3.2 Combining technologies

As we’ve described, a stable, narrow side channel entrainment zone suggests that a behavioral barrier may work in a given junction. In this report, we searched for a combination of tidal, hydrological conditions and junction geometry that naturally produced such conditions. However, rather than depend on optimal streakline positions to occur naturally, we can envision controlling an operable gate to maintain the optimal streakline position for a given behavioral barrier as is shown schematically (Figure 52). For example, even though the flows are reversing at the Head of Old River, the gate opening could be simply operated on the basis of the discharge ratio (\( Q_{sj}/Q_{old} \sim 0.5 \)) between the flow in Old River and San Joaquin River, so that the optimal streakline position is maintained (Figure 52). The gate could be closed during converging and reversing conditions, periods where the behavioral barrier shown would not work. Opening the gate during positive flow conditions could potentially reduce specific conductance levels, as fresher water tends to be transported at the end of the ebb tide. This approach may not allow much water to enter Old River during very low flow San Joaquin River flows but it may allow more water to flow into the South Delta than the culverts that are currently placed in the temporary barrier there. Specific operations would have to be explored using numerical modeling under various export rates and San Joaquin River flows to determine the impacts on maintaining water levels and water quality (e.g. electrical conductivity) for agriculture in this
region. Using a combination of technologies at this location may work well during non-drought conditions and should be studied with numerical models.

In addition, an operable barrier allows for the possibility of being able to take advantage of fish behavior, such as migrating by night, holding by day behavior.

4.3.3 Understanding the influence of San Joaquin River inflows and exports on the hydrodynamics in Turner and Columbia Cuts

As we described in the introduction of this report, collecting hydrodynamic data during low San Joaquin River inflows as an initial behavioral barrier scoping exercise at Turner and Columbia Cuts is OK. Nevertheless, if we want to understand precisely how the net and tidal flows in these junctions are influenced by San Joaquin River inflows and exports as we did for the San Joaquin River at Prisoners Point (Figure 3 and Figure 4), and within Turner Cut (Figure 2) then the SL-ADCP deployments in Figure 53 and Figure 54 are recommended for periods when exports and the San Joaquin River inflows are high and independently variable. These ADCP deployments will allow us to compare the effect of elevated and variable Vernalis and export flows on both the San Joaquin River upstream of Columbia and Turner Cut as well as within these channels.
REFERENCES


California Department of Water Resources. In Review. 2012 Georgiana Slough Non-Physical Barrier


APPENDIX. DATA PROCESSING, DISCHARGE ESTIMATION, AND COMPARISON

A.1 SL-ADCP DATA PROCESSING

The methods for processing SL-ADCP data have been described (Stumpner 2013a) and are briefly summarized here. The processing routines for the SL-ADCP profile data include geo-referencing, objective filtering of biased data, extrapolating velocity vectors in the horizontal and vertical, estimating small data gaps, and merging all data onto a common timestamp. General data processing and 2D velocity interpolation routines were developed in MATLAB. Tables A1-A3 shows the site parameters used to geo-reference the SL-ADCP data.

Table A1. Site Parameters for each SL-ADCP location at HOR and the SJTC pilot study

<table>
<thead>
<tr>
<th>Site</th>
<th>HORe</th>
<th>HORs</th>
<th>HORu</th>
<th>SJTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easting (m)</td>
<td>647149</td>
<td>647211</td>
<td>647412</td>
<td>636911</td>
</tr>
<tr>
<td>Northing (m)</td>
<td>4185729</td>
<td>4185878</td>
<td>4185753</td>
<td>4206365</td>
</tr>
<tr>
<td>Instrument Heading (°)</td>
<td>349</td>
<td>60</td>
<td>220</td>
<td>20</td>
</tr>
<tr>
<td>Blank (m)</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Bin Size (m)</td>
<td>1.33</td>
<td>1.33</td>
<td>1.33</td>
<td>3.33</td>
</tr>
<tr>
<td>Number of Bins</td>
<td>27</td>
<td>27</td>
<td>27</td>
<td>27</td>
</tr>
</tbody>
</table>

Three SL-ADCP’s were deployed at HOR from July 8 – October 29, 2013 (Figure 17). The data was continuous for sites HORe and HORs. At HORu there was large data gap that could not be estimated from September 12 – September 19, 2014. The SL-ADCP’s at HOR were only able to profile approximately 50 % of the cross-section or less, due to the shallow water depth (3-4 m). Previous data collected at HOR (Stumpner 2013b) was under higher discharge conditions (28 – 133 m³/s or 988 -4693 ft³/s) and the SL-ADCP profiles covered more of the cross-section. The accuracy of the extrapolated cross-sectional velocity vectors and the accuracy of the interpolated
velocity field will be somewhat compromised because less than 50\% of the cross-section was measured.

The data from the SL-ADCP deployed at SJTC (for the pilot study) was continuous from March 12 – October 29, 2013 (Figure 18; Table A1). This instrument was deployed only as an index velocity meter to provide an estimate of discharge.

Table A.2. Site Parameters for SL-ADCP’s and UL-ADCP’s at SJCC

<table>
<thead>
<tr>
<th>Site</th>
<th>CCdd</th>
<th>CCds*</th>
<th>CCdu</th>
<th>CCud</th>
<th>CCus</th>
<th>CCuu</th>
<th>CCe*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easting (m)</td>
<td>631804</td>
<td>631847</td>
<td>631972</td>
<td>632333</td>
<td>632282</td>
<td>632413</td>
<td>632339</td>
</tr>
<tr>
<td>Northing (m)</td>
<td>4210894</td>
<td>4210812</td>
<td>4219771</td>
<td>4210259</td>
<td>4210200</td>
<td>4210127</td>
<td>4210675</td>
</tr>
<tr>
<td>Instrument Heading (°)</td>
<td>30</td>
<td>N/A</td>
<td>40</td>
<td>80</td>
<td>150</td>
<td>37</td>
<td>N/A</td>
</tr>
<tr>
<td>Blank (m)</td>
<td>2.00</td>
<td>N/A</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
<td>N/A</td>
</tr>
<tr>
<td>Bin Size (m)</td>
<td>3.25</td>
<td>N/A</td>
<td>2.50</td>
<td>3.00</td>
<td>2.10</td>
<td>3.25</td>
<td>N/A</td>
</tr>
<tr>
<td>Number of Bins</td>
<td>27</td>
<td>N/A</td>
<td>27</td>
<td>27</td>
<td>27</td>
<td>27</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* UL-ADCP deployment used only to develop index velocity rating

Five SL-ADCP’s and two UL-ADCP’s were deployed at SJCC from November 14, 2013 – January 22, 2014 at the SJCC (Figure 19; Table A2). The data is continuous at CCud, and CCe. There are data gaps of several days for most sites, as the result of communications cables being severed. The primary cause of this was determined to be an animal, most likely beavers. At CCdd there is one data gap from 12/22/2013- 01/03/2014, at CCdu there is one data gap from 11/29 - 12/06/2013, at CCus there is one data gap from 01/02 - 01/04/2014, at CCuu there are three data gaps from 11/14 – 11/20/2013, 12/02 – 12/06/2013, and 01/09 – 01/11/2014, and at CCds there is one data gap from 11/14 – 11/26/2013. Despite the large number of data gaps there was continuous data at each junction for two of the three sites. The mass balance errors were low enough at each junction that discharge for missing time periods can be reasonably approximated.
and a time-series of discharge ratio and critical streakline can be estimated for the entire study period. Interpolated velocity fields will be limited to time periods where full data set exists.

**Table A.3.** Site Parameters for each SL-ADCP location at SJTC.

<table>
<thead>
<tr>
<th>Site</th>
<th>TCdde</th>
<th>TCddw</th>
<th>TCds</th>
<th>TCdue</th>
<th>TCduw</th>
<th>TCud</th>
<th>TCus</th>
<th>TCuu</th>
<th>TCe*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easting (m)</td>
<td>636144</td>
<td>635962</td>
<td>636017</td>
<td>636237</td>
<td>636114</td>
<td>636364</td>
<td>636425</td>
<td>636654</td>
<td>636446</td>
</tr>
<tr>
<td>Northing (m)</td>
<td>4207188</td>
<td>4206992</td>
<td>4206792</td>
<td>4207061</td>
<td>4206831</td>
<td>4206698</td>
<td>4206479</td>
<td>4206515</td>
<td>4207104</td>
</tr>
<tr>
<td>Instrument Heading (°)</td>
<td>235</td>
<td>207</td>
<td>300</td>
<td>237</td>
<td>32</td>
<td>35</td>
<td>312</td>
<td>29</td>
<td>N/A</td>
</tr>
<tr>
<td>Blank (m)</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>N/A</td>
</tr>
<tr>
<td>Bin Size (m)</td>
<td>2.50</td>
<td>1.60</td>
<td>1.25</td>
<td>2.50</td>
<td>1.00</td>
<td>4.00</td>
<td>1.00</td>
<td>2.50</td>
<td>N/A</td>
</tr>
<tr>
<td>Number of Bins</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* UL-ADCP deployment used only to develop index velocity rating

Eight SL-ADCP’s and one UL-ADCP were deployed from May 12 – July 29, 2014 at SJTC (Figure 20; Table 3). The data set at SJTC was only continuous at TCdde, TCddw, and TCdde. There are at least several day gaps at the remaining sites. The primary cause of data gaps is vegetation growth in front of the instruments that caused acoustic beam interference. The data gap periods are as follows: TCds there are two data gaps from 5/12 – 6/17/2014 and 6/21 – 6/23/2014; at TCud there is one data gap from 5/18 – 6/19/2014; at TCus there are two data gaps from 6/3 – 6/19/2014 and 7/6 – 7/17/2014; at TCuu there is one data gap from 5/12 – 5/30/2014.

The UL-ADCP at TCe only provided data until the end of March due to battery issues.

Calibration measurements taken on 7/21/2014 show that this channel conveys about 5 % of the water that flows down the San Joaquin, so the loss of this data set is not crucial. The large data gaps do not prevent assessment of junction scale entrainment for this time period. The low mass balance errors allow discharge to be accurately estimated for sites with large data gaps. The interpolated velocity fields will be limited to time periods when full data series exist.
A.2 UL-ADCP DATA PROCESSING

Two UL-ADCP’s were deployed at SJCC and one at SJTC (Full Study). These instruments record data internally and are powered by a battery pack attached to the frame. Once the instrument is recovered at the end of the study period, then the data can be downloaded and processed. Data processing routines were developed in MATLAB. The primary purpose of the UL-ADCP was to record an index velocity, the data processing was minimal.

The UL-ADCP data is recorded in earth coordinate system, since the instrument has an internal compass. The principle flow directions (i.e. flood and ebb) were determined from histogram plots of the entire data record. After this the data is rotated into an along-stream (x-component) and cross-stream (y-component) coordinate system. For the index velocity regression only the x-component of velocity is used. The tidal variation at these study sites is on the order of one to two meters, therefore the number of bins used to calculate the index velocity will vary. The water surface is determined by finding a spike in the intensity signal, every velocity value that is recorded above this is discarded for the mean velocity calculation.

A.3 2D VELOCITY INTERPOLATION

A Lagrangian particle tracking and inverse path-length weighting (IPLW) interpolation algorithms was implemented to interpolate the 2D velocity fields at the HOR, SJCC and SJTC junctions (Stumpner 2013a, Stumpner 2013b). An initial velocity field is generated using inverse distance weighted grid interpolation. Pathlines are then generated in this velocity field. For pathlines that cross measurement locations, the velocity magnitude and direction are interpolated along these pathlines using an inverse path-length weighting (IPLW) function:
\[ U(x) = \frac{\sum_{i=0}^{N} w_i(x) u_i}{\sum_{i=0}^{N} w_i(x)} \quad (1) \quad \quad w_i(x) = \frac{1}{d(x,x_i)^P} \quad (2) \]

Where \( U(x) \) is the interpolated velocity at point \( x \), \( u_i \) is a known velocity at point \( i \), at a distance \( d \) from the interpolated point \( x \). The number of points \( (N) \) used in the interpolation are weighted by the inverse distance from the interpolated point, by the weighting parameter \( (w_i) \), which can adjusted by the power parameter \( (P) \).

The number of pathlines that cross each measurement location are counted and if the ratio of particles \( (P_r) \) in two river branches is within 10% of the discharge ratio \( (Q_r) \) then the algorithm converges. If \( P_r - Q_r > 10\% \) then the pathline generation and IPLW interpolation is repeated, until the convergence criteria is met or the maximum number of iterations is reached.

**A.3.1 Boundary Conditions and Interpolation Parameters**

The boundary conditions and parameters are needed for the interpolation algorithm. The first boundary condition needed is the location of the river banks, which are determined from the bathymetry. At the river banks the velocity is assumed to be zero, following the no-slip condition. For the 2D interpolation only the surface velocity vectors are used. The surface velocity vectors are defined as the average velocity 0-2m below the water surface. These velocity vectors are time variable as the water surface elevation (WSE) changes. Several variables are unique to each junction, the weighting parameter \( (P) \) from equation 2, the distance between each grid node, and the discharge estimation either from the IVM or VPM. The discharge estimation is used to for the convergence criteria. The maximum number of iterations before the solution converges was set to 5 based on previous work (Stumpner, 2013a).
A.4 DISCHARGE MEASUREMENT, ESTIMATION AND COMPARISON

Discharge was computed with two methods, the index velocity method (*IVM*) and the velocity profile method (*VPM*). The *IVM* is a well-established technique for computing discharge (Ruhl and Simpson 2005; Levesque and Oberg 2012). In this case, the *VPM* was used to improve the accuracy of the critical streakline, since biased estimates can result using discharge from the *IVM*. The methodology from the *VPM* is outlined in Burau and Stumper (2013). Because the *VPM* approach relies on direct numerical integration of the velocity profile the calculated discharge is free of calibration errors but the accuracy of the VPM is sensitive to accuracy of extrapolation of the velocity profile in the vertical and the unmeasured portion of the cross section in the cross channel direction (Le Coz, Pierrefeu et al. 2008). The *VPM* is not a well-established method for computing discharge. To validate this approach we compared discharge computed using both methods.

Moving boat measurements were made with a down-looking (DL) ADCP at each site to develop index velocity and stage-area ratings to compute a discharge time-series using the *IVM*. The DL-ADCP discharge measurement produces a cross-sectional average velocity and area. A linear regression with the cross-sectional velocity and averaged SL-ADCP velocity is made to determine the index velocity rating. The stage area rating is developed based on a DL-ADCP measurement that is fairly straight during high tide on the measurement day. The bathymetry from that measurement is imported into AreaComp ([http://hydroacoustics.usgs.gov/indexvelocity/AreaComp.shtml](http://hydroacoustics.usgs.gov/indexvelocity/AreaComp.shtml)). A quadratic stage-area rating is developed for the range of stage measurements from the SL-ADCP. A time series of index velocity (*V*) and cross-sectional area (*A*) is computed with the SL-ADCP data, and the product of these two produce an estimated discharge (*Q = A·V*).
In this section we examine the accuracy of the VPM as compared to the IVM. The metrics that we used for a discharge comparison are:

1. Mass balance from the three river branches
2. Least squared regression

For the mass balance metric we compared the tidally averaged data to average out possible large errors that may have occurred in low discharge conditions and potential ebb/flood bias. The mass balance is determined from six idealized discharge conditions (Burau and Stumpner, 2013; Fig. A1). At a junction the sum of the discharges is equal to the change in storage within the junction, or \( \sum_{i=1}^{l} Q_i = \Delta S \). Because these junctions are small and the water levels change over a period of roughly 12 hours, the incremental change in storage within the junctions on the 15 minute sampling interval is negligible, so we assume the change in storage is zero, or \( \sum_{i=1}^{l} Q_i = 0 \). For each discharge scenario the sum of two channels (\( Q_2 \)) should equal the one channel (\( Q_1 \)) that is either receiving the discharge or distributing the discharge to the other two channels. Least squared regressions are run between the two methods to test the accuracy of VPM with the more accepted method IVM.

A.4.1 Head of Old River

Due to instrument problems encountered at the start of data collection, DL-ADCP measurements taken to calibrate the SL-ADCP’s using the index velocity method (IVM) could not be made at the Head of Old River. Therefore, DL-ADCP measurements at the instrument locations (HORe, HORs, and HORu) were linearly fit to estimated discharge data from long-term gages near the project site, DWR stations OH1, SJD, and MSD, respectively (Figure A56, Figure A57, Figure A58).
The discharge at HORu was estimated with a linear regression with San Joaquin River at Mossdale (MSD) approximately 4.5 km upstream of the site, with a 40 minute time offset applied to account for this distance. The time shift was determined by the best $R^2$ value over a range of time shifts. A non-linear regression ($2^{nd}$ order polynomial) showed a better statistical correlation ($R^2 = 0.993$) than the linear regression ($R^2 = 0.978$), but the non-linear relationship did a poor job in predicting negative discharges that were outside of the rating, therefore the linear regression was used to estimate a time-series of discharge (Figure A56).

The discharge at HORe was estimated with a linear regression with Old River at Head (OH1) approximately 0.25 km downstream of the site, with no time offset applied. The linear regression showed a good fit ($R^2 = 0.97$), and close to a 1:1 relationship with OH1 (Figure A57), therefore there is greater confidence in extrapolating outside of the rating limit.

The discharge at HORs was estimated with a linear regression with San Joaquin near Dos Reis (SJD) approximately 3 km downstream of the site, with a 10 minute offset applied to account for this distance. The linear regression showed an excellent fit ($R^2 = 0.996$). The relationship was not exactly 1:1, but the goodness of fit and the lack of spread from the regression line improves the confidence in this rating (Figure A58).

The mass balance errors between the $IVM$ and $VPM$ for discharge estimation compare favorably (see Table A4). The mean differences in mass balance calculations for both methods is $\sim15\%$ indicating the neither method did a great job of accurately estimating junction-wide discharge at this location.
Table A4. Tidally averaged error statistics for mass balance calculations at HOR

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean Square Error(^1) (m(^3)/s)</th>
<th>Standard Deviation (m(^3)/s)</th>
<th>Mean Difference(^1) (%)</th>
<th>Standard Deviation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVM</td>
<td>4.94</td>
<td>2.53</td>
<td>13.59</td>
<td>6.53</td>
</tr>
<tr>
<td>VPM</td>
<td>-4.11</td>
<td>3.65</td>
<td>-15.34</td>
<td>12.41</td>
</tr>
</tbody>
</table>

\(^1\) Positive values indicate Q\(_1\) > Q\(_2\) and Negative values indicate Q\(_1\) < Q\(_2\)

At HORu, the VPM adequately compares to the IVM, but there is a lot of spread at low and reversing discharge conditions. Overall, the VPM is not a good predictor of discharge computed with the IVM at this location (Figure A59). At HORs, the VPM compares favorably to the IVM, although the VPM under predicts at higher positive discharge and slightly under predicts during reversing conditions (Figure A60). At HORe, the VPM compares favorably to the IVM, although there is a lot of spread in the relationship and reversing discharge conditions the VPM under predicts the IVM and the relationship is non-linear (Figure A61).

The main reason for the discrepancies between the VPM and the IVM are believed to be horizontal extrapolation errors, and the reasons are two-fold. First, the complexity of the discharge at HOR and the fact that the measurement sites are close to a river junction most likely resulted in ebb-flood asymmetry in the cross-sectional velocity distribution. Anecdotal evidence from field observations during reversing discharge conditions at HORu shows stronger water velocities on the left bank. Second, at HORs and HORu <50% of the cross-section was measured and at HORu ~50% of the cross-section was measured which makes accurate extrapolations difficult, especially with asymmetrical cross channel velocity profiles.
A.4.2 San Joaquin River near Turner Cut - Pilot study

The IVM was used to derive a discharge time-series estimate at SJTC, based on DL-ADCP measurements on May 24, 2013. The linear regression was made with bins 1-14 (out of 27) from the SL-ADCP, as a regression including all bins showed a looping effect. The linear regression showed good correlation ($R^2=0.99$) with the measured velocity from discharge measurements, although some scatter exists at velocities near zero (Figure A62). The measured discharge only covered a range of values from -570 - 350 m$^3$/s, and the range of discharge estimated is from -655 - 790 m$^3$/s. There is a considerable range at the high end of the positive discharge that is not covered by the index rating. Nonetheless the IVM provides a good estimate of discharge for the measured range at the site. Discharge data from Turner Cut was available from a USGS gage station.

A.4.3 San Joaquin River near Columbia Cut

The IVM was used to derive discharge time-series estimates at all seven of the sites at SJCC, based on DL-ADCP measurements on January 14 and 16, 2014.

The index velocity rating at CCdd was made with a linear regression of all bins (1-27) from the SL-ADCP. The linear regression showed an excellent correlation ($R^2 = 0.995$) and a near 1:1 ration with the measured velocity, with the highest scatter in the lower velocities (Figure A63). The stage area rating was developed with the DL-ADCP transect taken at 16:55 on January 16, 2014. The stage area rating is: $Area = 2.5 \times stage^2 + 131.8 \times stage + 411$.

The index velocity rating at CCds was made with a linear regression from UL-ADCP averaged velocity with the number of bins used ranging from six to twelve. The linear regression is not great ($R^2=0.923$) with a lot of spread in the data (Figure A64). The stage area rating was
developed with the DL-ADCP transect taken at 15:40 on January 16, 2014. The stage area rating is: \[ \text{Area} = 11.07 \times \text{stage}^2 + 84.9 \times \text{stage} + 92. \] Observations during the DL-ADCP measurements and initial deployment of the UL-ADCP revealed that there is a lot of vegetation in this channel, therefore discharge and velocity measurements are difficult since the vegetation interferes with the acoustic beams on the boat mounted DL-ADCP. The flow at this site is one order of magnitude less than the adjacent channel, therefore extremely accurate flow measurement are not needed to evaluate junction hydrodynamic features.

The index velocity rating at CCdu was made with a linear regression of bins (1-20) from the SL-ADCP. The linear regressions shows a good correlation (\( R^2 = 0.994 \)), a near 1:1 ratio with the measured velocity and the highest scatter in the lower velocities (Figure A65). The stage area rating was developed with the DL-ADCP transect taken at 16:35 on January 16, 2014. The stage area rating is \[ \text{Area} = 5.9 \times \text{stage}^2 + 100.7 \times \text{stage} + 351. \]

The index velocity rating at CCe was made with a linear regression from UL-ADCP averaged velocity with the number of bins used ranging from nine to thirteen. The linear regression shows a good correlation (\( R^2 = 0.978 \)), but some spread in the data (Figure A66). The stage area rating was developed with the DL-ADCP transect taken at 15:40 on January 16, 2014. The stage area rating is: \[ \text{Area} = 11.5 \times \text{stage}^2 + 75.8 \times \text{stage} + 65. \] Observations during the DL-ADCP measurements and initial deployment of the UL-ADCP revealed that there some vegetation in this channel, complicating the accuracy of velocity and discharge measurements. The flow at this site is about a factor of five less than the adjacent channel.

The index velocity rating at CCud was made with a linear regression from bins (1-20) from the SL-ADCP. The linear regression shows a good correlation (\( R^2 = 0.995 \)) with the measured
velocity with a little scatter at the positive peak velocities (Figure A67). The stage area rating was developed with the DL-ADCP transect taken at 15:10 on January 14, 2014. The stage area rating is \( \text{Area} = 4.6 \times \text{stage}^2 + 104.0 \times \text{stage} + 151.4 \).

The index velocity rating at CCus was made with a linear regression from all bins (1-27) from the SL-ADCP. The linear regression shows a good correlation (\( R^2 = 0.971 \)) with the measured velocity, although it is the weakest of the all the ratings and statistically there is more scatter in the data (Figure A68). During DL-ADCP measurements an eddy on the right bank was noted, that could be contributing to the error in the index velocity rating, since the SL-ADCP could not measure the full cross-section. The stage area rating was developed with the DL-ADCP transect taken at 11:15 on January 14, 2014. The stage area rating is \( \text{Area} = 1.4 \times \text{stage}^2 + 81.8 \times \text{stage} + 249 \).

The index velocity rating at CCuu was made with a linear regression from all bins (1-27) from the SL-ADCP. The linear regression shows a good correlation (\( R^2 = 0.989 \)) with the measured velocity, although it is not as strong as the other sites and statistically there is more scatter in the data (Figure A69). The stage area rating was developed with the DL-ADCP transect taken at 13:55 on January 14, 2014. The stage area rating is \( \text{Area} = 4.4 \times \text{stage}^2 + 126.2 \times \text{stage} + 623.1 \).

Mass balance errors are examined for the three river junctions as defined in Figure 3. Based on mass balance calculations the IVM is a more accurate estimate of discharge at junctions 1 and 2 and the IVM and VPM are equally accurate at junction 3.

Least square regressions between the IVM and VPM are made for the five sites with SL-ADCP’s. For all five sites the IVM and VPM discharge estimations correlate well with \( R^2 \geq 0.994 \). At CCdd the VPM under predicts discharge calculated by the IVM for positive and
negative discharge values (Figure A70). This under prediction is greater at CCdu (Figure A71). At CCud the VPM and IVM follow nearly a 1:1 ratio, except during higher positive discharge the VPM slightly over predicts discharge (Figure A72). At CCus the 1:1 relationship is very good and little spread except during negative discharge conditions (Figure A73). At CCuu there 1:1 relationship is good, but more spread in the data and the VPM under predicts slightly at negative discharge values (Figure A74). Overall the VPM does a good job at predicting discharge as calculated by the IVM at all sites.

**Table A5.** Tidally averaged error statistics for mass balance calculations at Columbia Cut

<table>
<thead>
<tr>
<th>Junction</th>
<th>Method</th>
<th>Mean Square Error (m$^3$/s)</th>
<th>Standard Deviation (m$^3$/s)</th>
<th>Mean Difference (%)</th>
<th>Standard Deviation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1</td>
<td>IVM</td>
<td>9.55</td>
<td>1.96</td>
<td>7.99</td>
<td>1.72</td>
</tr>
<tr>
<td></td>
<td>VPM</td>
<td>17.95</td>
<td>2.48</td>
<td>-17.38</td>
<td>2.95</td>
</tr>
<tr>
<td>J2</td>
<td>IVM</td>
<td>8.58</td>
<td>1.04</td>
<td>-10.19</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>VPM</td>
<td>14.21</td>
<td>3.57</td>
<td>-19.56</td>
<td>5.76</td>
</tr>
<tr>
<td>J3</td>
<td>IVM</td>
<td>5.41</td>
<td>1.06</td>
<td>5.24</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td>VPM</td>
<td>4.09</td>
<td>1.79</td>
<td>-4.95</td>
<td>2.24</td>
</tr>
</tbody>
</table>

**A.4.4 San Joaquin at Turner Cut – Full Study**

The IVM was used to derive discharge time-series estimates at six sites at SJTC, based on DL-ADCP measurements on July 21, 2014.

The index velocity rating at TCdde was made with a linear regression of bins (1-37) from the SL-ADCP. The linear regression showed good correlation ($R^2 = 0.984$) but a looping effect is apparent during positive flow conditions (Figure A75). The stage area rating was developed with the DL-ADCP transect taken at 16:42 on July 21, 2014. The stage area rating is: \( Area = 5.0 \ast stage^2 + 163.7 \ast stage + 1183 \). Observations of the DL-ADCP measurements show that several
of the measurements that fall off the index rating curve (Figure A75) have higher velocities near the bottom of the river than near the surface. This could possible explain the looping effect since the SL-ADCP was positioned to measure near surface water currents.

The index velocity rating at TCddw was made with a linear regression of bins (1-45) from the SL-ADCP. The linear regression showed good correlation ($R^2 = 0.971$) but there is scatter at both positive and negative values (Figure A76). There are eddies that form on either side of the channel during flood and ebb tides. It is possible that the SL-ADCP is not capturing the full extent of these eddies and therefore the index velocity rating could be biased during these conditions. The stage area rating was developed with the DL-ADCP transect taken at 15:59 on July 21, 2014. The stage area rating is: \[ Area = 2.95 \times stage^2 + 89.92 \times stage + 361.13. \]

The index velocity rating at TCds was made with a linear regression of bins (4-40) from the SL-ADCP. The DL-ADCP measurements were taken 140 m upstream of the SL-ADCP, therefore the DL-ADCP measurements were shifted by 6 minutes to account for the travel time. The linear regression showed good correlation ($R^2 = 0.971$) but there is a fair amount of scatter throughout the rating curve (Figure A77). The stage area rating was developed with the DL-ADCP transect taken at 15:59 on July 21, 2014. The stage area rating is: \[ Area = 4.17 \times stage^2 + 63.31 \times stage + 188.35. \]

The index velocity rating at TCus is made with a linear regression of bins (1-35) from the SL-ADCP. The linear regression shows an excellent correlation ($R^2 = 0.993$) and there is minimal scatter and no looping effects (Figure A78). The stage area rating was developed with the DL-ADCP transect taken at 17:05 on July 21, 2014. The stage area rating is: \[ Area = 2.14 \times stage^2 + 50.85 \times stage + 89. \]
The index velocity rating at TCuu was made with a linear regression of bins (1-40) from the SL-ADCP. The linear regression showed good correlation ($R^2 = 0.980$) but the index velocity overestimates at higher positive values and underestimates at higher negative values (Figure A79). A non-linear relationship was a better predictor of measured discharge for this day, but there was enough velocity outside the range of calibration that we felt it was a poor choice for predicting discharge for the entire record. The stage area rating was developed with the DL-ADCP transect taken at 13:35 on July 21, 2014. The stage area rating is:

$$ Area = 7.72 \times \text{stage}^2 + 199.44 \times \text{stage} + 1288. $$

Mass balance errors for both the *IVM* and *VPM* are good, with the *IVM* showing slightly larger mean errors but the standard deviation is less (Table A6). For this junction both methods provide reliable discharge predictions using the mass balance metric.

*Table A6.* Tidally averaged error statistics for mass balance calculations at Turner Cut

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean Square Error$^1$ (m$^3$/s)</th>
<th>Standard Deviation (m$^3$/s)</th>
<th>Mean Difference$^1$ (%)</th>
<th>Standard Deviation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVM</td>
<td>-16.90</td>
<td>6.19</td>
<td>-5.48</td>
<td>1.97</td>
</tr>
<tr>
<td>VPM</td>
<td>9.12</td>
<td>14.26</td>
<td>2.61</td>
<td>4.21</td>
</tr>
</tbody>
</table>

Least square regressions between the *IVM* and *VPM* for discharge estimation are made for the five sites with SL-ADCP’s that had index velocity ratings. For all five sites the *IVM* and *VPM* discharge estimations have good correlations with $R^2 \geq 0.94$. At TCdde the *VPM* follows nearly a 1:1 relationship with the *IVM*, except at higher negative discharge values (Figure A80). The *VPM* over predicts the discharge for these conditions. At TCddw there is quite a bit of scatter for positive discharge conditions, and at negative discharge conditions the *VPM* over predicts discharge by a factor of two at higher negative values (Figure A81). At TCds the *VPM* over
predicts discharge for the entire range (Figure A82). At TCus the VPM over predicts discharge for the entire range (Figure A83), but the relationship is very good with very little scatter. At TCuu the VPM shows a nearly 1:1 relationship with the IVM, with a bit more scatter at higher negative discharge (Figure A84), but overall the relationship is very good.

The VPM does a good job predicting flow at the sites in the main channel, TCdde and TCuu. The VPM is not as reliable a predictor of discharge at the side channel sites, TCd, TCddw, and TCus. The magnitude of discharge is one order of magnitude lower in the side channel sites, therefore using the VPM estimate of discharge should provide acceptable results for water entrainment at this junction. Given the good statistical correlation between the IVM and VPM, as well as the low error in the mass balance at the junction, sites with large periods of missing data can be reasonably estimated.
Figure 1. Map of the Sacramento/San Joaquin Delta with the locations of junctions studied for this report. Study locations are indicated by red circles.
Figure 2. Time Series plot of (A) tidal (blue) and net (red) discharge at Turner Cut and (B) San Joaquin river discharge at Vernalis (green) and at net discharge Turner Cut (same as above, red) and export rate (black).
Figure 3. Time Series plot of (A) tidal (blue) and net (red) discharge at the San Joaquin River at Prisoners Point and (B) San Joaquin river discharge at Vernalis (green) and at net discharge Prisoners Point (same as above, red) and export rate (black).
Figure 4. Time series plot of (A) San Joaquin River discharge @ Vernalis (green), exports (black), and (B) the ratio of the net flow $<Q>$ to $<Q'>$ tidal range at Prisoner’s Point (red) and Turner Cut (blue).
Figure 5. Conceptual diagram of entrainment in a junction. Red regions denote the entrainment zone for the side channel whereas the green regions show the region where fish continue along the main channel. The red line between these regions is the critical streakline. Top panel shows the required conditions for fish to “go with the flow” – in this case the bulk discharge in each channel. These conditions include a uniform entrance fish spatial distribution AND behaviors that don’t result in fish crossing the critical streakline. In the bottom panel are indicated those conditions that create conditions where fish aren’t distributed in proportion to the flows in each channel. These conditions include a non-uniform entrance fish distribution as is shown and behaviors that cause fish to transit the critical streakline.
Figure 6. Conceptual schematic showing conditions that are conducive to behavioral barriers (some of which are interdependent): (1) small ratios of side channel to main channel cross sectional areas ($A_{sc}/A_{mc} << 1$), (2) small and temporally stable discharge ratios ($Q_{sc}/Q_{mc} << 1$), (3) non-uniform spatial distributions, where $A_{sc}$, $A_{mc}$ are the side channel and main channel cross sectional areas, respectively, and $Q_{sc}$, $Q_{mc}$ are the side channel and main channel cross sectional discharges. If the up-current spatial distributions are biased toward the side channel (spatial distribution B) then entrainment in the junction is likely to be minimal in the absence of a barrier AND there would be very few fish for a behavioral barrier to move across the streakline to reduce entrainment. Therefore, because population level survival is the product of the entrainment rate (low in the case of a spatial distribution biased away from the side channel - B above) AND reach specific survival (which is low in the delta) the impact on population level survival of a behavioral barrier under these conditions is likely to be minimal and therefore not recommended.
Figure 7. Bathymetry plot of Turner Cut, which suggests that the bypass flow in the San Joaquin is likely large relative to the flows in either North or South Turner Cuts. Based on channel capacity arguments, the North Turner Cut conveys most of the water into Turner Cut on flood tides and South Turner Cut conveys water on ebb tides as is indicated by the arrows.
Figure 8. Bathymetry plot of Columbia Cut, which suggests that the bypass flow in the San Joaquin is likely large relative to the flows into Columbia Cut. Based on channel capacity arguments, the South Columbia Cut conveys most of the water into Columbia Cut, as is indicated by the arrows.
Figure 9. Bathymetry plot of Head of Old River, which suggests that since the channel capacity in the mainstem San Joaquin River and Old River very near identical that the tidal timescale bypass flow in the San Joaquin is likely on the order of the flow in Old River at this junction.
Figure 10. The paths of taken by drifters (yellow lines) deployed during the 2011 BAFF™ experiment by the Department of Water Resources during converging flow conditions at the Georgiana Slough junction with the Sacramento River. (Data courtesy of Dave Huston, DWR). The critical streakline is shown as a red line.
Figure 11. The paths of taken by drifters (yellow lines) deployed during the 2011 BAFF™ experiment by the Department of Water Resources during downstream flow conditions (Data courtesy of Dave Huston, DWR). The critical streakline is shown as a red line.
Figure 12. Definition sketch defining the three flow conditions that occur in a tidally forced junction where the water is entering a side channel: (1) downstream flow in the main channel, (2) converging flow, and (3) upstream flow.
Figure 13. Definition sketch defining the three flow conditions that occur in a tidally forced junction where the water is exiting a side channel: (1) downstream flow in the main channel, (2) converging flow, and (3) upstream flow.
Figure 14. Schematic showing hydrodynamic conditions that suggest a behavioral barrier will not work: (A) the critical streakline is significantly across the main channel from the side channel, (B) critical streakline is highly temporally variable (e.g. not stable), (C) the velocity distributions are converging into the side channel for a significant fraction of the tidal period, (D) the up-current fish spatial distribution is on the side opposite the side channel. We can’t evaluate condition (D) with the existing data but would need to deploy and evaluate 2D acoustic telemetry data to assess this condition.
Figure 15. Conceptual schematic of two barrier alignments and the relationship between the channel velocity and barrier orientation, where $U_a$ is the channel velocity, $U_e$ is the fish escape velocity, and $U_s$ is the sweeping velocity component along the face of the barrier (Turnpenny and O’Keeffe 2005).
Figure 16 Conceptual schematic of the “relaxation” of the fish spatial distribution downstream of a behavioral barrier. This figure is completely conceptual since the research has not been done to verify the “relaxation” length scale, however, we know that, at some point, there exists a downstream distance where the fish spatial distribution is independent of the effects of the barrier. Shown is a fish entrance distribution that is biased to the side channel shore (label 1 above). As this distribution interacts with the barrier, it is biased to the bank opposite the side channel across the streakline (label 2), if the barrier is affective. However, once the fish move past the trailing edge of the barrier, this distribution begins to “relax” (Label 3). Lateral mixing due to natural river hydraulics such as surface boils, eddies off the trailing edge of the barrier and behavior likely all contribute to this relaxation. Therefore, behavioral barriers should not be placed to far upstream of the side channel entrance.
Figure 17. Aerial view of Head of Old River showing location of SL-ADCP’s (HORe, HORs, and HORu), and parameters used for critical streakline calculations. The positive flow directions are indicated by white arrows.
Figure 18. Ariel view of San Joaquin River near Turner Cut (Pilot Study) showing location of discharge measurements (SJTC and TRN). Parameters used critical streakline calculations (Qu, Qs, Qd, Wu, and Wd). The positive flow directions are indicated by white arrows.
Figure 19. Ariel view of San Joaquin River near Columbia Cut showing location of SL-ADCP’s (red dots and line) and locations of UL-ADCP’s (green dots). Each junction in the study area is labeled (J1, J2, and J3). Positive flow direction for each channel is indicated by yellow arrows.
Figure 20. Aerial view of San Joaquin River near Turner Cut (Full Study) showing locations of SL-ADCP’s (red dots and lines) and UL-ADCP (green dot). Positive flow direction for each channel is indicated by white arrows.
Figure 21. Time series data estimated using the velocity profile method for discharge calculation and integral method for discharge ratio and critical streakline calculation at HOR (a, top panel) tidally filtered discharge upstream (black), downstream (blue) and side channel (red) (b, middle panel) discharge ratio at upstream (black), downstream (blue) and total (red) and (c, bottom panel) critical streakline in distance from upstream left bank (black) and downstream left bank (blue).
Figure 22. Upstream and downstream critical streakline positions at HOR. The solid line represents the mean critical streakline from the left and the dashed line represents one standard deviation from the mean.
Figure 23. Non-linear regression of the critical streakline from the left bank estimated from the discharge ratio and integral methods (a) at HORu; for positive flow conditions only and (b) at HORs; for negative flow conditions only.

(a) 

- Number of data points = 6180
- Squared correlation coefficient = 0.972
- $y = 1.0237 \times x + 3.5992$
- RMS error of prediction = 6.0357

(b) 

- Number of data points = 3747
- Squared correlation coefficient = 0.715
- $y = -0.0090 \times x^2 + 1.5591 \times x + 6.8337$
- RMS error of prediction = 5.7700
Figure 24. Timeseries data estimated using the index velocity method for discharge calculation and the discharge ratio method for discharge ratio and critical streakline calculation at SJTC (a) tidally filtered discharge upstream (black), downstream (blue) and side channel (red) (b) tidally filtered discharge ratio at upstream (black), downstream (blue) and total (red) and (c) tidally filtered critical streakline in distance from upstream left bank (black) and downstream left bank (blue). Note negative critical streakline indicate flow from side channel to main channel.
Figure 25. Time series data estimated using the velocity profile method for discharge calculation and integral method for discharge ratio and critical streakline calculation at SJCC (a) tidally filtered discharge upstream (black), downstream (blue) and side channel (red) (b) tidally filtered discharge ratio at upstream (black), downstream (blue) and total (red) and (c) tidally filtered critical streakline in distance from upstream left bank (black) and downstream left bank (blue). Note negative critical streakline indicate flow from side channel to main channel.
Figure 26. Upstream and downstream critical streakline positions at SJCC as reference from the left bank. The solid line represents the mean critical streakline and the dashed line represents one standard deviation from the mean.
Figure 27. Non-linear regression of the critical streakline from the left bank at estimated from the discharge ratio and integral methods at CCuu; for positive flow. Note the locations of the critical streakline using the integral method is discretized into bins equal to the measurement bin spacing (3.06 m)
Figure 28. Time series data estimated using the velocity profile method for discharge calculation and the integral method for discharge ratio and critical streakline calculations at SJTC (a) tidally filtered discharge upstream (black), downstream (blue) and side channel (red) (b) tidally filtered discharge ratio at upstream (black), downstream (blue) and total (red) and (c) tidally filtered critical streakline in distance from upstream left bank (black) and downstream left bank (blue). Note negative critical streakline indicate flow from side channel to main channel.
Figure 29. Upstream and downstream critical streakline positions at SJTC as reference from the left bank. The solid line represents the mean critical streakline and the dashed line represents one standard deviation from the mean.
Figure 30. Non-linear regression of the critical streakline from the left bank estimated from the discharge ratio and integral methods (a) at TCuu; for positive flow conditions only and (b) at TCddw; for negative flow conditions only. Note outliers outside of 2 standard deviations from the regression curve were removed.
Figure 31. Histogram plot of the difference in flow ratio (Qr) and particle ratio (Pr) for velocity interpolation algorithm at HOR for (a) all data (b) positive discharge conditions (c) negative discharge conditions.
Figure 32. Interpolated Velocity Vectors overlain on bathymetry plot at HOR for typical positive flow conditions.
Figure 33. Interpolated Velocity Vectors overlain on bathymetry plot at HOR for typical negative flow conditions.
Figure 34. Histogram plot of the difference in flow ratio (Qr) and particle ratio (Pr) for velocity interpolation algorithm at SJCC junction 1 for (a) all data (b) positive discharge conditions (c) negative discharge conditions.
Figure 35. Interpolated Velocity Vectors overlain on bathymetry plot at SJCC junction 1 for typical positive flow conditions.
Figure 36. Interpolated Velocity Vectors overlain on bathymetry plot at SJCC junction 1 for typical negative flow conditions.
Figure 37. Histogram plot of the difference in flow ratio (Qr) and particle ratio (Pr) for velocity interpolation algorithm at SJTC for (a) all data (b) positive discharge conditions (c) negative discharge conditions.
Figure 38. Interpolated Velocity Vectors overlain on bathymetry plot at SJTC for typical positive flow conditions.
Figure 39. Interpolated Velocity Vectors overlain on bathymetry plot at SJTC for typical negative flow conditions.
Figure 40. Tidally filtered discharge measured data (blue) and modeled data (black) at (a) HORu (b) HORs and (c) HORe.
Figure 41. Linear Regression of model discharge vs. measured discharge at HORu. Modeled data is phase corrected by +0.25 hours.

Number of data points = 10984
Squared correlation coefficient = 0.921
y = 1.3752 *x + -9.2627
RMS error of prediction = 7.8192
Figure 42. Linear Regression of model discharge vs. measured discharge at HORs. Modeled data is phase corrected by -0.25 hours.
Figure 43. Linear Regression of model discharge vs. measured discharge at HORe. Modeled data is phase corrected by -0.5 hours.

Number of data points = 10987
Squared correlation coefficient = 0.880
\[ y = 0.9356 \times x + 2.0606 \]
RMS error of prediction = 6.2196
Figure 44. Histogram plots of amplitude errors between measured and modeled data. Data is separated based on tidal phase; top panels are during positive discharge and bottom panels are during negative discharge at (a,d) HORu (b,e) HORs and (c,f) HORe. Number in the top left corner indicate mean amplitude differences for that site and discharge range.
Figure 45. Time series data for SJTC (a) 15 min average discharge estimated from measured data (blue) and from model (black) (b) Tidally filtered discharge from measured data (blue) and model data (black).
Figure 46. Histogram plots of amplitude errors between measured and modeled data at SJTC. Data is separated based on tidal phase (a) top panel is positive discharge values and (b) bottom panel is negative discharge values.
Figure 47. Linear Regression of model discharge vs. measured discharge at SJTC. Modeled data is not phase corrected.
Figure 48 Comparison of entrainment rates, $\psi$, and survival, $S$, between acoustically tagged juvenile salmon taking an Old River route through the central delta versus remaining in the mainstem San Joaquin based on 6-year study data collected in 2010 (Courtesy of Rebecca Buchanan).
Figure 49 Comparison of entrainment rates, \( \psi \), and survival, \( S \), between acoustically tagged juvenile salmon taking an Old River route through the central delta versus remaining in the mainstem San Joaquin based on 6-year study data collected in 2011 (Courtesy of Rebecca Buchanan).
Figure 50. Ariel View of Columbia Cut and suggested placement of behavioral barriers. Option 1 would be placed where data was collected but may be at either too steep of an angle or be unnecessarily long. Option 2 presumably would have the same effect but be significantly small, and therefore more cost effective. White arrows indicate relative magnitude of flow and direction during positive flow conditions. The main stem San Joaquin flows are roughly four times the flow in the CCuu and the flow in Columbia Cut is about half of that.
Figure 51. Ariel View of Turner Cut and suggested placement of behavioural barriers yellow lines. The two Negative flow barriers are suggested instead of a barrier inside of TCddw, since most of the flow from TCddw enters TCds on the flood tide. White arrows indicate relative magnitude of flow on the main steam San Joaquin relative to Turner Cut. The double ended arrow in Turner Cut indicates that during the ebb tide there is both positive and negative flow at Turner Cut. The relevant sites are labeled as well.
Figure 52. Schematic of combining a technologies. An operable barrier that modulates the flow so that the streakline is in an optimal position for an upstream behavioral barrier. The ration of the discharges, Q_old/Q_sj, collected from a pair of SL-ADCP’s shown are used to control the gate position.
Figure 53. SL-ADCP deployment schematic showing two SL-ADCP’s which can be used in combination with the permanent USGS flow station TRN(Q) above to understand the influence of high San Joaquin River inflows and exports on the hydrodynamics of the Turner Cut junction.
Figure 54. SL-ADCP deployment schematic showing four SL-ADCP’s which can be used to understand the influence of high San Joaquin River inflows and exports on the hydrodynamics of the Columbia Cut junction.
Figure 55. Location of USGS-maintained flow and water quality stations in the Sacramento/San Joaquin Delta.
Appendix Figures

Figure A56. Linear regression of flow measured at MSD and flow measured at HORu.
Figure A57. Linear regression of flow measured at SJD and flow measured at HORs.
Figure A58. Linear regression of flow measured at OH1 and flow measured at HORe.
Figure A59. Linear regression of flow measured HORu using the gage regression (IVM) and the velocity profile method (VPM).

Number of data points = 9279
Squared correlation coefficient = 0.866
\[ y = 0.8951 \times x + 0.4294 \]
RMS error of prediction = 8.1823
Figure A60. Linear regression of flow measured at HORs using the gage regression (IVM) and the velocity profile method (VPM).
Figure A61. Linear regression of flow measured HORe using the gage regression (IVM) and the velocity profile method (VPM).

Number of data points = 10026
Squared correlation coefficient = 0.842
\[ y = 1.0851 \times x - 4.3275 \]
RMS error of prediction = 7.2303
Linear Regression of index velocity measured at SJTC and measured cross-sectional velocity.

Number of data points = 39
Squared correlation coefficient = 0.990
\[ y = 1.0956 \times x + 0.0139 \]
RMS error of prediction = 0.0200

**Figure A62.** Linear Regression of index velocity measured at SJTC and measured cross-sectional velocity.
Figure A63. Linear Regression of index velocity measured at CCdd and measured cross-sectional velocity.
Figure A64. Linear Regression of index velocity measured at CCds and measured cross-sectional velocity.

- Number of data points = 33
- Squared correlation coefficient = 0.923
- \( y = 0.6540 \times x - 0.0049 \)
- RMS error of prediction = 0.0096
Figure A65. Linear Regression of index velocity measured at CCdu and measured cross-sectional velocity.

Number of data points = 28
Squared correlation coefficient = 0.994
\[ y = 0.9935 \times x - 0.0108 \]
RMS error of prediction = 0.0142
Figure A66. Linear Regression of index velocity measured at CCe and measured cross-sectional velocity.
Figure A67. Linear Regression of index velocity measured at CCud and measured cross-sectional velocity.

- Number of data points = 28
- Squared correlation coefficient = 0.995
- \( y = 0.8644 \times x + -0.0056 \)
- RMS error of prediction = 0.0112
Figure A68. Linear Regression of index velocity measured at CCUs and measured cross-sectional velocity.
Figure A69. Linear Regression of index velocity measured at CCuu and measured cross-sectional velocity.
Figure A70. Linear regression of flow measured CCdd using the gage regression (IVM) and the velocity profile method (VPM). Dashed red line indicates 1:1 correlation.
Figure A71. Linear regression of flow measured CCdu using the gage regression (IVM) and the velocity profile method (VPM). Dashed red line indicates 1:1 correlation.
Figure A72. Linear regression of flow measured CCud using the gage regression (IVM) and the velocity profile method (VPM). Dashed red line indicates 1:1 correlation.
Figure A73. Linear regression of flow measured CCus using the gage regression (IVM) and the velocity profile method (VPM). Dashed red line indicates 1:1 correlation.
Figure A74. Linear regression of flow measured CCuu using the gage regression (IVM) and the velocity profile method (VPM). Dashed red line indicates 1:1 correlation.
**Figure A75.** Linear Regression of index velocity measured at TCdде and measured cross-sectional velocity.
Figure A76. Linear Regression of index velocity measured at TCddw and measured cross-sectional velocity.
Figure A77. Linear Regression of index velocity measured at TCds and measured cross-sectional velocity.
Figure A78. Linear Regression of index velocity measured at TCus and measured cross-sectional velocity.
Figure A79. Linear Regression of index velocity measured at TCuu and measured cross-sectional velocity.
**Figure A80.** Linear regression of discharge estimated TCdde using the velocity profile method (VPM) as a predictor of the index velocity method (VPM). Dashed red line indicates 1:1 correlation.
Figure A81. Linear regression of flow measured TCddw using the index velocity method (IVM) and the velocity profile method (VPM).
Figure A82. Linear regression of flow measured TCds using the index velocity method (IVM) and the velocity profile method (VPM).
Figure A83. Linear regression of flow measured TCus using the index velocity method (IVM) and the velocity profile method (VPM).
Figure A84. Linear regression of flow measured TCuu using the index velocity method (IVM) and the velocity profile method (VPM).
Modeling Physical Barriers (Gates) as Engineering Solutions to Satisfy NMFS BiOp RPA Action IV.1.3

October, 2014

Subir K Saha

Bay Delta Office

Department of Water Resources
1. Introduction

This report provides detailed modeling information on the potential impact on flow, water quality and water level throughout the Delta of physical barriers (gates) as engineering solutions to deter fish from entering the Delta. The modeling was performed to provide information to support decision making for engineering solutions to satisfy the NMFS BiOp RPA Action IV.1.3 (Action). The Action objective is to prevent emigrating Salmonids from entering into the Interior and Southern Delta, and to reduce exposure to the CVP and SWP export facilities. Delta Simulation Model 2 (DSM2) was used to simulate gates on the Delta channels: Georgiana Slough, Head of Old River, Turner Cut and Columbia Cut. The modeling results have been evaluated for impact analysis of flow, water quality, and water level throughout the Delta.

2. The Simulation Model

DSM2 is a one-dimensional hydrodynamic and water quality model used to simulate hydrodynamics, water quality, and particle tracking in the Sacramento-San Joaquin Delta. DSM2 represents the best available planning model for Delta tidal hydraulic and salinity modeling. It is appropriate for describing the existing conditions in the Delta, as well as performing simulations for the assessment of incremental environmental impacts caused by future facilities and operations.

DSM2 consists of three modules: HYDRO, QUAL, and PTM. HYDRO simulates flow, velocities and water level and provides the flow input for QUAL and PTM. DSM2-HYDRO outputs are used to predict changes in flow rates, water level, and their effects on Delta channels as a result of future facilities and operations.

QUAL module simulates fate and transport of conservative and non-conservative water quality constituents, including salts, given a flow field simulated by HYDRO. Outputs are used to estimate changes in salinity and their effects on Delta channels as a result of future facilities and operations.

The DSM2-PTM module, not used in this modeling analysis, simulates pseudo 3-D transport of neutrally buoyant particles based on the flow field simulated by HYDRO. It simulates the transport and fate of individual particles traveling throughout the Delta. PTM has multiple applications ranging from visualization of flow patterns to simulation of discrete organisms such as fish eggs and larvae. Additional information on DSM2 can be found on the DWR Modeling Support Branch website at http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm

3. Methodology

There were several scenarios investigated during this analysis ranging from full flow blockage to partial flow blockage at four key junctions in the Delta (Figure 1). An additional key junction, Threemile Slough,
for which prior analysis had been conducted and is discussed in this report, is not shown on the Figure 1. The purpose of the flow blockage is to simulate a gate blocking a junction to divert emigrating Salmonids from entering into the Delta channels and to keep them in the Sacramento River or San Joaquin River for their passage to the Ocean. The 16-year (Water Year 1976 – Water Year 1991) DSM2 model was used to simulate these scenarios. The 16-year DSM2 model simulations have also been used for the Bay Delta Conservation Plan (BDCP) Draft EIR/S, South Delta Improvements Program (SDIP), Franks Tract Project, Storage Investigations and Operations Criteria and Plan (OCAP). The DSM2 model simulation of Existing Conditions for the BDCP Draft EIR/EIS was used as a baseline. The modeled or simulated flow, water quality, and water level were then compared with the baseline and the incremental changes were evaluated for impacts on various Delta locations.

Figure 1: Gate locations in the Delta channels.
3.1. Description of Existing Condition

The Existing Conditions model simulation was developed assuming Year 2009 level of development and regulatory conditions. The Existing Conditions assumptions included existing facilities and ongoing programs that existed as of February 13, 2009 (publication date of the BDCP Public EIR/EIS Notice of Preparation and Notice of Intent) could affect or could be affected by implementation of the Alternatives. The Existing Conditions assumptions also included assumptions related to the State Water Project (SWP) and Central Valley Project (CVP), ongoing policies by governmental and non-profit entities, and assumptions related to annual actions that vary every year. One exception to this was the NMFS Biological Opinion on the Long-Term Central Valley Project and State Water Project Operations Criteria and Plan (BiOp), released in June 2009, was included in the development of the Existing Conditions simulation (BDCP Public EIR/EIS, 2013).

3.2. Description of Modeling Scenarios

The modeling scenarios were developed by adding a gate, or a combination of gates, to the Existing Conditions model simulation. The scenarios were divided into three categories: Full flow blockage to Delta Channels, Partial Flow Blockage to Delta Channels, and Flow Blockage used in other Projects. The gates in these scenarios were operated either by Flow trigger or Velocity trigger option to restrict flow to the Delta channels. The scenarios which included Georgiana Slough or Head of Old River gate had gate operation trigger location either in the Delta channels or in the Rivers. The scenarios which included Turner Cut and Columbia Cut gate had trigger location only in the Delta channels. These channels are located in Central Delta and are influenced by the tide. It was assumed that the impact from trigger location in the Rivers for these gates would be similar to that of the channels. Table 1 lists the categories with gate locations and operations for each of the scenarios.

Table 1: Modeling scenarios of gate location and operation

<table>
<thead>
<tr>
<th>Category</th>
<th>Location of Gate</th>
<th>Gate Operation Trigger</th>
<th>Trigger Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Flow Blockage to Delta Channels</td>
<td>Georgiana Slough, Head of Old River, Turner Cut &amp; Columbia Cut (Four Gates)</td>
<td>Closed on positive flow in channel &amp; opened on reverse flow</td>
<td>Flow in Georgiana Slough, Head of Old River, Turner Cut &amp; Columbia Cut</td>
</tr>
<tr>
<td></td>
<td>Georgiana Slough</td>
<td>Closed on positive flow in channel &amp; opened on reverse flow</td>
<td>Flow in Georgiana Slough</td>
</tr>
<tr>
<td></td>
<td>Head of Old River</td>
<td>Closed on positive flow in channel &amp; opened on reverse flow</td>
<td>Flow in Head of Old River</td>
</tr>
<tr>
<td></td>
<td>Turner Cut</td>
<td>Closed on positive flow in channel &amp; opened on reverse flow</td>
<td>Flow in Turner Cut</td>
</tr>
<tr>
<td></td>
<td>Columbia Cut</td>
<td>Closed on positive flow in channel &amp; opened on reverse flow</td>
<td>Flow in Columbia Cut</td>
</tr>
<tr>
<td>Category</td>
<td>Location of Gate</td>
<td>Gate Operation Trigger</td>
<td>Trigger Location</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>------------------------------------------------------------</td>
<td>-----------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Head of Old River, Turner Cut &amp; Columbia Cut (Three Gates)</td>
<td>Closed on positive flow in channel &amp; opened on reverse flow</td>
<td>Flow in Head of Old River, Turner Cut &amp; Columbia Cut</td>
<td></td>
</tr>
<tr>
<td>Georgiana Slough, Head of Old River, Turner Cut &amp; Columbia Cut (Four Gates)</td>
<td>Closed on ebb &amp; opened on flood</td>
<td>Flow in Sacramento River, San Joaquin River, Turner Cut &amp; Columbia Cut</td>
<td></td>
</tr>
<tr>
<td>Georgiana Slough</td>
<td>Closed on ebb &amp; opened on flood</td>
<td>Flow in Sacramento River</td>
<td></td>
</tr>
<tr>
<td>Head of Old River</td>
<td>Closed on ebb &amp; opened on flood</td>
<td>Flow in San Joaquin River</td>
<td></td>
</tr>
<tr>
<td>Head of Old River, Turner Cut &amp; Columbia Cut (Three Gates)</td>
<td>Closed on ebb &amp; opened on flood</td>
<td>Flow in San Joaquin River</td>
<td></td>
</tr>
<tr>
<td>Partial Flow Blockage to Delta Channels</td>
<td>Partial closed on ebb to block 50% net flow &amp; opened on flood</td>
<td>Flow in Sacramento River</td>
<td></td>
</tr>
<tr>
<td>Georgiana Slough</td>
<td>Closed on high velocity &amp; Opened on low velocity</td>
<td>Velocity in Sacramento River</td>
<td></td>
</tr>
<tr>
<td>Georgiana Slough</td>
<td>Partial closed on high velocity to block 50% net flow &amp; opened on low velocity</td>
<td>Velocity in Sacramento River</td>
<td></td>
</tr>
<tr>
<td>Head of Old River</td>
<td>Closed on high velocity &amp; Opened on low velocity</td>
<td>Velocity in San Joaquin River</td>
<td></td>
</tr>
<tr>
<td>Head of Old River</td>
<td>Partial closed on high velocity to block 50% net flow &amp; opened on low velocity</td>
<td>Velocity in San Joaquin River</td>
<td></td>
</tr>
<tr>
<td>Flow Blockage used in other Projects</td>
<td>Franks Tract Project proposed operation, Seasonal operation for Fish and Water Quality</td>
<td>Flow in Sacramento and San Joaquin River or EC in Jersey Point</td>
<td></td>
</tr>
</tbody>
</table>

**3.2.1. Full Flow Blockage to Delta Channels:**

The gates were modeled to restrict flow from entering into the junctions. The gates at one, or a combination of sites, were modeled in this category. The gates’ operations were triggered by either flow in the Delta channels where the gates were placed, or flow in the Rivers. The gates with trigger location in Delta channels were closed on the positive flows in the channels and were opened on reverse flow in the channels. The gates with trigger location in the Sacramento or San Joaquin River are described below as flow trigger.
3.2.1.1. **Flow Trigger:**

The gates were closed on the ebb tide when the water flowed towards the Ocean from the Rivers. The gates were opened on the flood tide when the water flowed from the Ocean towards the Rivers. The gate operation at Georgiana Slough was used to illustrate the flow trigger method. The trigger was based on the flow in the Sacramento River downstream of the gate. When the flow direction at the Sacramento River at the trigger location was towards the Ocean, the Georgiana Slough gate was closed. The gate was opened during reverse flow periods. Figure 2 illustrates the gate closure in response to the flow trigger. The gate operation at the Head of Old River was based on the flow in the San Joaquin River downstream of the gate. The gate operation scenario was similar to the Georgiana Slough gate.

![Figure 2: Flow triggered gate operation (open/close)](image)

3.2.2. **Partial Flow Blockage to Delta Channels:**
The gates were modeled to restrict partial flow from entering into the junctions. The gates were placed in the junctions on Delta channels. In this category, flow was not fully blocked to enter into the channels from the Rivers during the ebb tide. The gates operations were triggered by either flow in the Rivers, or velocity in the Rivers. These triggers were described below.

### 3.2.2.1. Flow Trigger:

During the ebb tide, the size of the gate was modified to attain an average flow blockage of about 50% over the 16-year model simulation period. The scenario was analyzed to evaluate incremental changes in water quality and water level. The gates were closed on the ebb tide when the water flowed towards the Ocean from the Sacramento or San Joaquin River. The gates were opened on the flood tide when the water flowed from the Ocean towards the Rivers. Figure 2 illustrates the flow trigger scenario for Georgiana Slough. The Head of Old River gate had similar operations.

### 3.2.2.2. Velocity Trigger:

The gate operation was triggered by velocity in the Rivers. The gate at a junction of a River and channel operated based on velocity in the River downstream of the junction. The velocity in the Delta followed the tidal cycle and has two high and two low velocities in every 6 hours. When the velocity changed from high to low, the gate was closed, and when the velocity changed from low to high, the gate was opened. Figure 3 illustrates the gate closure in response to the velocity trigger. The gate at Georgiana Slough operated based on a velocity trigger in the Sacramento River downstream of the junction. Another scenario which blocked about 50% of the flow during the gate closure period (Figure 3) was simulated. This modeling scenario was developed by modifying the size of the gate. The gate at the Head of Old River was operated on a similar velocity trigger formulation, but it was based on the velocity in the San Joaquin River downstream of the junction.
3.2.3. Flow Blockage used in other Projects:

As noted under 3. Methodology, prior gate modeling analysis had already been conducted for Threemile Slough (Franks Tract Project). The Franks Tract Project objectives were different than the objective of NMFS BiOp RPA Action IV.1.3 but one of the objectives was to protect sensitive fish species and reduce seawater intrusion through modifications of flow conditions in the western Delta. The proposed Franks Tract Project includes a tidally operated gate located in the Threemile Slough. The Franks Tract DSM2 model was re-ran for this study analysis to simulate the proposed gate operations. The modeling results were analyzed for any impacts on the Delta.

4. Model Results:
The DSM2 model was simulated for 16 years for Existing Conditions and all scenarios listed in Table 1. The model results were in 15 minutes intervals and were processed to generate monthly average flow, monthly average EC (used for salinity), and daily minimum water level. The percentage of time that the gates were closed throughout the simulation period is reported in Table 2 for all scenarios.

Table 2: Gate closure frequency

<table>
<thead>
<tr>
<th>Category</th>
<th>Location of Gate</th>
<th>Gate Operation Trigger</th>
<th>Trigger Location</th>
<th>Percent of time gate was closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Flow Blockage to Delta Channels</td>
<td>Georgiana Slough, Head of Old River, Turner Cut &amp; Columbia Cut (Four Gates)</td>
<td>Closed on positive flows in channel &amp; opened on reverse flows</td>
<td>Flow in Georgiana Slough, Head of Old River, Turner Cut &amp; Columbia Cut</td>
<td>99, 99, 51 &amp; 50</td>
</tr>
<tr>
<td></td>
<td>Georgiana Slough</td>
<td>Closed on positive flows in channel &amp; opened on reverse flows</td>
<td>Flow in Georgiana Slough</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>Head of Old River</td>
<td>Closed on positive flows in channel &amp; opened on reverse flows</td>
<td>Flow in Head of Old River</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>Turner Cut</td>
<td>Closed on positive flows in channel &amp; opened on reverse flows</td>
<td>Flow in Turner Cut</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>Columbia Cut</td>
<td>Closed on positive flows in channel &amp; opened on reverse flows</td>
<td>Flow in Columbia Cut</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Head of Old River, Turner Cut &amp; Columbia Cut (Three Gates)</td>
<td>Closed on positive flows in channel &amp; opened on reverse flows</td>
<td>Flow in Head of Old River, Turner Cut &amp; Columbia Cut</td>
<td>99, 51 &amp; 50</td>
</tr>
<tr>
<td></td>
<td>Georgiana Slough, Head of Old River, Turner Cut &amp; Columbia Cut (Four Gates)</td>
<td>Closed on ebb &amp; opened on flood</td>
<td>Flow in Sacramento River, San Joaquin River, Turner Cut &amp; Columbia Cut</td>
<td>80, 80, 51 &amp; 50</td>
</tr>
<tr>
<td></td>
<td>Georgiana Slough</td>
<td>Closed on ebb &amp; opened on flood</td>
<td>Flow in Sacramento River</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Head of Old River</td>
<td>Closed on ebb &amp; opened on flood</td>
<td>Flow in San Joaquin River</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Head of Old River, Turner Cut &amp; Columbia Cut (Three Gates)</td>
<td>Closed on ebb &amp; opened on flood</td>
<td>Flow in San Joaquin River, Turner Cut &amp; Columbia Cut</td>
<td>80, 51 &amp; 50</td>
</tr>
<tr>
<td>Partial Flow Blockage to Delta</td>
<td>Georgiana Slough</td>
<td>Partial closed on ebb to block 50% net flow &amp; opened on flood</td>
<td>Flow in Sacramento River</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Head of Old River</td>
<td>Partial closed on ebb to block 50% net flow &amp; opened on flood</td>
<td>Flow in San Joaquin River</td>
<td>80</td>
</tr>
<tr>
<td>Category</td>
<td>Location of Gate</td>
<td>Gate Operation Trigger</td>
<td>Trigger Location</td>
<td>Percent of time gate was closed</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>--------------------------------</td>
<td>----------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>Channels</td>
<td></td>
<td>block 50% net flow &amp; opened on flood</td>
<td>River</td>
<td></td>
</tr>
<tr>
<td>Georgiana Slough</td>
<td>Closed on high velocity &amp; Opened on low velocity</td>
<td>Velocity in Sacramento River</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>Georgiana Slough</td>
<td>Partial closed on high velocity to block 50% net flow &amp; opened on low velocity</td>
<td>Velocity in Sacramento River</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>Head of Old River</td>
<td>Closed on high velocity &amp; Opened on low velocity</td>
<td>Velocity in San Joaquin River</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Head of Old River</td>
<td>Partial closed on high velocity to block 50% net flow &amp; opened on low velocity</td>
<td>Velocity in San Joaquin River</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Flow Blockage used in other Projects</td>
<td>Threemile Slough (Franks Tract Project)</td>
<td>Franks Tract Project proposed operation, Seasonal operation for Fish and Water Quality</td>
<td>Flow in Sacramento and San Joaquin River or EC in Jersey Point</td>
<td>12</td>
</tr>
</tbody>
</table>

The modeled flow for the scenarios was compared with Existing Conditions at downstream locations of the gate in Georgiana Slough, Head of Old River, Columbia Cut and Turner Cut. The modeled EC was compared at Sacramento River at Emmaton (Emmaton), San Joaquin River at Jersey Point (Jersey Point), Clifton Court Forebay (Clifton Court), and Old River at Tracy Road (Tracy Road). The modeled water level (stage) was compared at Old River at Tracy Road, San Joaquin River at Brandt Bridge (Brandt Bridge), and San Joaquin River at Prisoners Point (Prisoners Point) (Figure 4). The processed values are presented in Figures 5 through 71.
4.1. Full Flow Blockage to Delta Channels:

The gates at Georgiana Slough and Head of Old River were closed for 99% of the time for the flow in the Delta channels trigger scenarios; therefore, little to no flow was going through these channels. The gates at Georgiana Slough and the Head of Old River were closed 80% of the time (Table 2) for the flow in the Rivers trigger scenarios. The gates were closed less frequently than the previous scenarios; therefore, little flow went through these channels. The gates at Columbia Cut and Turner Cut were closed or opened 50% of the time. Figure 5 through Figure 20 showed monthly average flow in the Delta channels downstream of the gates. A positive flow direction in Columbia and Turner Cut refers to flow towards...
the San Joaquin River, and a negative flow direction refers to flow from the San Joaquin River into the Cuts.

Figure 21 through Figure 36 showed monthly average EC comparison bar plots. The Georgiana Slough gate and Four Gates scenarios (see Table 1) blocked better quality Sacramento River flow from entering into the Interior and Southern Delta, and allowed more water to flow through the Sacramento River. This flow pattern had an impact on water quality. EC at Clifton Court and Jersey Point increased, and EC at Emmaton decreased. The Head of Old River gate and Three Gates scenarios (see Table 1) had no impact on EC at Emmaton, Jersey Point, or Clifton Court.

The Delta Cross Channel (DCC) gates were fully closed from February 1st through May 20th in accordance with the State Water Resources Control Board Decision 1641 (Bureau of Reclamation). The DCC gates were closed for a total of 14 days from May 21st through June 15th. During those months, the model showed that the Head of Old River gate and Three Gates scenarios deteriorated EC at Tracy Road, but improved or had no impacts on EC for all other months. The Four Gates scenario increased EC at Tracy Road. The Georgiana Slough gate had no impact on EC at Tracy Road. The Columbia Cut gate and Turner Cut gate scenarios had no impact on EC at these locations. Therefore, no further modeling of partial flow blockage scenarios for Columbia Cut and Turner Cut gates were necessary.

Daily minimum water levels at the South Delta locations were evaluated (Figure 37 to Figure 48). The Head of Old River gate dropped the water level by 1 foot or more during most years of the 16 year simulation period. The Head of Old River gate restricted San Joaquin flows from entering Old River and left more water in the San Joaquin River. As a consequence, the water level at Brandt Bridge increased by 1 foot or more 40% of the time. The water level at Prisoners Point, which is 45 miles downstream from the gate site, did not change. All of the other gate scenarios did not have an impact on water level in the South Delta.

### 4.2. Partial Flow Blockage to Delta Channels:

For the flow trigger scenarios, with the 50% flow blockage on the ebb tide, more Sacramento River water went into Georgiana Slough, and more San Joaquin River water went into Old River (Figure 17 to Figure 20).

For the velocity trigger scenarios, the gates were closed 46% of the time in Georgiana Slough, and 45% of the time at Head of Old River (Table 2). As expected, flow was less restricted to these channels (Figure 49 to Figure 52).

EC at Clifton Court and Jersey Point increased in response to the Georgiana Slough gate operations. EC at Emmaton decreased, and there was no impact at Tracy Road. The velocity trigger scenarios had a smaller impact on EC (Figure 53 to Figure 56) than the flow trigger scenarios (Figure 33 to Figure 36).
The combined effects of the DCC gate and the Head of Old River gate closures deteriorated EC from February to May at Tracy Road. There were no impacts to EC at Emmaton, Jersey Point, and Clifton Court.

The Georgiana Slough gate didn’t have an impact on water level in the South Delta. The impacts on water level in the South Delta channels, due to the Head of Old River gate, were similar in trends as compared with the previous scenarios, but the magnitudes of changes were smaller. The velocity trigger scenarios had a smaller impact on water level (Figure 57 to Figure 59) than the flow trigger scenarios (Figure 46 to Figure 48).

4.3. Flow Blockage used in other Projects:

The Franks Tract Project proposed gate at Threemile Slough was operated seasonally for water quality and fishery benefits. The gate improved water quality in Clifton Court and Jersey Point, and had no impact on water quality in Emmaton and Tracy Road. The gate had no impact on water level in the South Delta (Figure 60 to Figure 67).

5. Conclusion:

The impacts of the Georgiana Slough, Head of Old River, Turner Cut and Columbia Cut gates on water quality and water level varied. Figure 68 through Figure 71 represented incremental changes in water quality throughout the Delta for each of the gates. The figures also showed relative impacts among the four different gates. Table 3 summarizes the impacts on water quality for all scenarios.

Table 3: Impacts of modeling scenarios on water quality

<table>
<thead>
<tr>
<th>Category</th>
<th>Location of Gate</th>
<th>Gate Operation Trigger</th>
<th>Impact on Water Quality (EC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Clifton Court</td>
</tr>
<tr>
<td>Full Flow Blockage to Delta Channels</td>
<td>Georgiana Slough, Head of Old River, Turner Cut &amp; Columbia Cut (Four Gates)</td>
<td>Closed on positive flow in channel &amp; opened on reverse flow</td>
<td>Deteriorated</td>
</tr>
<tr>
<td>Georgiana Slough</td>
<td>Closed on positive flow in channel &amp; opened on</td>
<td></td>
<td>Deteriorated</td>
</tr>
<tr>
<td>Category</td>
<td>Location of Gate</td>
<td>Gate Operation Trigger</td>
<td>Clifton Court</td>
</tr>
<tr>
<td>----------</td>
<td>-----------------</td>
<td>------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Head of Old River</td>
<td>Clifton Court</td>
<td>reverse flow</td>
<td>No/minimal</td>
</tr>
<tr>
<td>Turner Cut</td>
<td>Clifton Court</td>
<td>reverse flow</td>
<td>No</td>
</tr>
<tr>
<td>Columbia Cut</td>
<td>Clifton Court</td>
<td>reverse flow</td>
<td>No</td>
</tr>
<tr>
<td>Head of Old River, Turner Cut &amp; Columbia Cut (Three Gates)</td>
<td>Clifton Court</td>
<td>reverse flow</td>
<td>No/minimal</td>
</tr>
<tr>
<td>Georgiana Slough, Head of Old River, Turner Cut &amp; Columbia Cut (Four Gates)</td>
<td>Clifton Court</td>
<td>reverse flow</td>
<td>Deteriorated</td>
</tr>
<tr>
<td>Georgiana Slough</td>
<td>Clifton Court</td>
<td>reverse flow</td>
<td>Deteriorated</td>
</tr>
<tr>
<td>Head of Old River</td>
<td>Clifton Court</td>
<td>reverse flow</td>
<td>No</td>
</tr>
<tr>
<td>Head of Old River, Turner Cut &amp; Columbia Cut (Three Gates)</td>
<td>Clifton Court</td>
<td>reverse flow</td>
<td>No/Minimal</td>
</tr>
<tr>
<td>Partial</td>
<td>Georgiana</td>
<td>Partial closed</td>
<td>Deteriorated</td>
</tr>
</tbody>
</table>
## Impact on Water Quality (EC)

<table>
<thead>
<tr>
<th>Category</th>
<th>Location of Gate</th>
<th>Gate Operation Trigger</th>
<th>Clifton Court</th>
<th>Emmaton</th>
<th>Jersey Point</th>
<th>Tracy Road</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Blockage to Delta Channels</td>
<td>Slough</td>
<td>on ebb to block 50% net flow &amp; opened on flood</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Head of Old River</td>
<td>Partial closed on ebb to block 50% net flow &amp; opened on flood</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Minimal*</td>
</tr>
<tr>
<td></td>
<td>Georgiana Slough</td>
<td>Closed on high velocity &amp; Opened on low velocity</td>
<td>Deteriorated</td>
<td>Improved</td>
<td>Deteriorated</td>
<td>No/Minimal</td>
</tr>
<tr>
<td></td>
<td>Georgiana Slough</td>
<td>Partial closed on high velocity to block 50% net flow &amp; opened on low velocity</td>
<td>Deteriorated</td>
<td>Improved</td>
<td>Deteriorated</td>
<td>No/Minimal</td>
</tr>
<tr>
<td></td>
<td>Head of Old River</td>
<td>Closed on high velocity &amp; Opened on low velocity</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Minimal*</td>
</tr>
<tr>
<td></td>
<td>Head of Old River</td>
<td>Partial closed on high velocity to block 50% net flow &amp; opened on low velocity</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Minimal*</td>
</tr>
<tr>
<td>Flow Blockage used in other Projects</td>
<td>Threemile Slough (Franks Tract Project)</td>
<td>Franks Tract Project proposed operation, Seasonal operation for Fish and Water Quality</td>
<td>Improved</td>
<td>No</td>
<td>Improved</td>
<td>No</td>
</tr>
</tbody>
</table>

* EC deteriorated at Tracy Road when both DCC and Head of Old River gates were closed.

The modeling analysis conclusions are:

- The impacts on water quality and water level decreased as gate closure time decreased.
➢ The Georgiana Slough Gate deteriorated water quality in the Central and South Delta, as well as in the SWP & CVP export facilities.

➢ The Georgiana Slough Gate improved water quality at Emmaton.

➢ The Head of Old River Gate deteriorated water quality locally, and caused lower water level in the South Delta.

➢ The Columbia and Turner Cut Gates had no impact on water quality or water level.

6. References:

