2-Gates Fish Protection Demonstration Project

Summary Document

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CALFED Science Program Independent Review Panel

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Table of Contents

Introduction **1**

Project Purpose and Background **1**

Project Purpose 1
Goals and Objectives 2
Adaptive Management Framework 4
Monitoring Framework 5

Conceptual Foundation **7**

Entrainment of Adult Delta Smelt 7
Turbidity Relationships 8
Dispersive Mixing 13
Conceptual Model 16

Key Questions & Hypothesis Testing **17**

Adult Delta Smelt Protection 21
Dispersive Mixing 25

Physical and Operational Elements **27**

Project Location 27
Gate Structures 27
Project Operations 28

References **36**

Appendices **39**

Appendix A. 2-Gates Fish Protection Demonstration Project Background and Regulatory Constraints

Appendix B. Particle Tracking and Analysis of Adult and Larval/Juvenile Delta Smelt for 2-Gates Fish Protection Demonstration Project

Appendix C. Sacramento-San Joaquin Delta Turbidity Modeling

Appendix D. Monitoring and Analysis to Determine if Elevated Turbities from the Sacramnto River Trigger Movement of Adult Delta Smelt

Appendix E. Fixed-Site Monitoring Associated with the 2-Gates Fish Protection Demonstration Project Operations

Figures

Figure 1. Regional location of 2-Gates Project

Figure 2. Adaptive Management Framework

Figure 3. Relationship between Occurrence of Delta Smelt and Turbidity and Cumulative Frequency of Capture

Figure 4. Relationship between Turbidity, Old and Middle River Flows, and Ddelta Smelt Salvage

Figure 5. Operation of 2-Gates Project to Reduce Adult Delta Smelt Entrainment by Balancing Turbidity Flux along Old and Middle Rivers

Figure 6. Longitudinal Profile of Modeled Turbidity along Old River from Franks Tract to Clifton Court Forebay

Figure 7. Operation of 2-Gates Project to Reduce Larval/Juvenile Delta Smelt Entrainment

Figure 8. Percent of Particles Entrained at CVP+SWP by Region during the Modeled Period

Figure 9. Conceptual Model of 2-Gates Project Inputs and Outcomes

Figure 10. Conceptual View of the Old River Facilities

Tables

Table 1. Hypotheses/Questions for the proposed 2-Gates Fish Protection Demonstration Project

Table 2. Initial operational scenarios for 2-Gates Fish Protection Demonstration Project

Introduction

This Summary Document has been prepared for the CALFED Science Program Independent Review Panel in response to a request from the Department of Water Resources and the U.S. Bureau of Reclamation. This document has been prepared specifically for independent science review, and has not been reviewed or approved by any State or Federal agency. The proposed 2-Gates Fish Protection Demonstration Project (2-Gates Project) seeks to provide equal or improved protection to delta smelt (reduced entrainment at the export pumps) with higher than the minimum allowed water exports described in the Operations Criteria and Plan (OCAP) Biological Opinions (BOs) Reasonable and Prudent Alternatives (RPAs) of the U.S. Fish and Wildlife Service and National Marine Fisheries Service, while operating within the other water management requirement (D-1641). The Project is consistent with both BO RPAs and all other water quality and management requirements.

Project Purpose and Background

PROJECT PURPOSE

The 2-Gates Project proposes an alternative management strategy to achieve protection of the delta smelt (*Hypomesus transpacificus*). The Central Valley Project (CVP) and State Water Project (SWP) operate under the OCAP and other water rights and water quality requirements (project background provided in Appendix A). These operations comply with the RPAs in the recent BOs for the OCAP from the U.S. Fish and Wildlife Service (FWS 2008) and National Marine Fisheries Service (NMFS 2009). The RPAs include actions to limit reverse flows in Old and Middle Rivers to reduce entrainment of fish at the CVP and SWP export facilities.

The Project seeks to provide equal or improved protection to delta smelt (reduced entrainment at the export pumps) with higher than the minimum allowed water exports described in the OCAP BO RPAs while operating within the other water management requirement (D-1641). In particular, the Project is intended to demonstrate that operable barriers, strategically placed in the central Delta and managed in conjunction with some restrictions on OMR negative flows, can provide equal or greater protection for delta smelt than restrictions on OMR negative flows alone. The proposed 2-Gates Project is designed as a demonstration project to test this premise and to improve understanding of the key physical and biological processes needed to restore a sustainable ecosystem.

The 2-Gates Project proposes to install and operate temporary, removable gates in two channels in the central Delta at Old River and Connection Slough (Figure 1). The gates will be used to manipulate flows and key water quality components of delta smelt habitat in order to reduce entrainment of delta smelt at the export facilities.

GOALS AND OBJECTIVES

The 2-Gates Project goals are:

- Goal 1 (overarching goal) - To provide equal or improved protection of delta smelt with higher than the minimum allowed water exports described in the OCAP BO RPAs while operating within the other water management requirements.
    - Reduce adult delta smelt entrainment in the export facilities by operating the gates to manipulate the turbidity flux in the central and western Delta to create a zone of lower turbidity in advance of the south Delta export facilities.
    - Reduce juvenile delta smelt entrainment in the facilities by transporting that portion of the population in the south and central Delta into the western Delta, through gate operations that enhance dispersive mixing.
- Goal 2 – To minimize adverse effects to other listed species or other resources in the Delta, including Sacramento River winter-run Chinook salmon (*Oncorhynchus tshawaytscha*), Central Valley spring-run Chinook salmon (*O. tshawytscha*), Central Valley steelhead (*O. mykiss*), North American green sturgeon (*Acipenser medirostris*), and longfin smelt (*Spirinchus thaleichthys*).

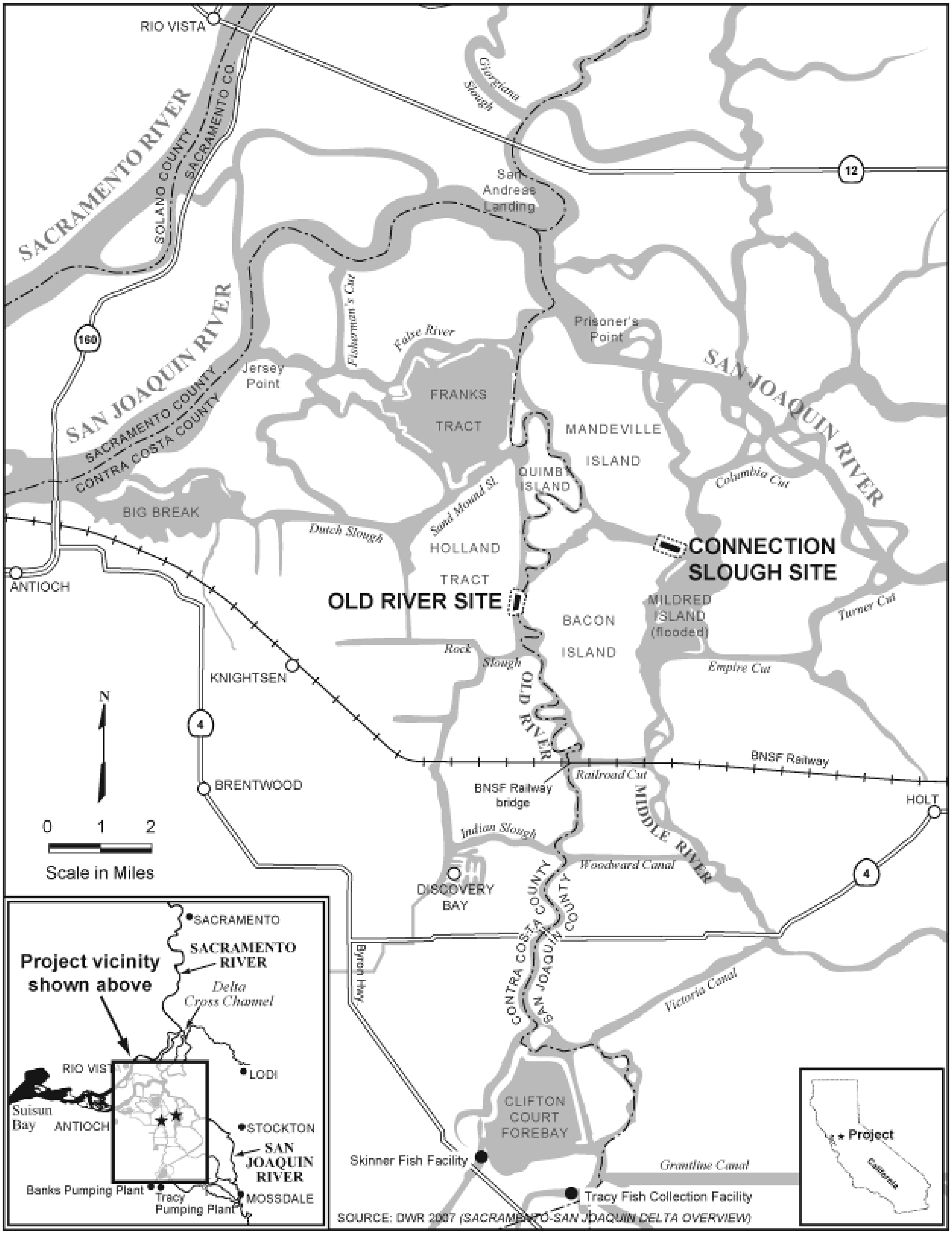

Figure 1. Regional location of 2-Gates Project.

This document provides an overview of the science underlying the Project's design to meet Goal 1. A separate Biological Assessment has been prepared to evaluate the potential effects on delta smelt and other listed species (Goal 2). The effects analysis will not be presented in this document. The reviewer is referred to the Draft BA for species information and the effects analysis.

ADAPTIVE MANAGEMENT FRAMEWORK

An adaptive management framework has been developed consistent with project goals to test hypotheses and monitor effects in order to refine understanding, modify hypotheses and improve operations (Figure 2). The concept of this project was developed through extensive modeling of hydrodynamic conditions, turbidity, and the effects on biological models (Appendices B and C). The Project is designed as an experiment to test hypotheses regarding the relationship of flows, water quality (turbidity) and delta smelt behavior and distribution. Tests would be conducted through iterative field operations. The Project includes a multi-parameter monitoring program to provide information for hypothesis testing and adaptive management (Appendix C in the BA). While it is the expectation that the experiment will demonstrate and provide higher than the minimum allowed water exports described in the OCAP BO RPAs, the experiment will operate fully within the flow requirements of the RPAs for the OCAP BO and other water management requirements.

The hypotheses testing and monitoring program will provide data to:

- Guide efficient operation of the Project (triggering conditions for gate operations).
- Assess Project effects on changes in local flow, turbidity, and salinity under different scenarios.
- Allow verification and testing of the models for future evaluation of operational changes and Delta improvements.
- Improve understanding of delta smelt biology and behavior in the Delta.

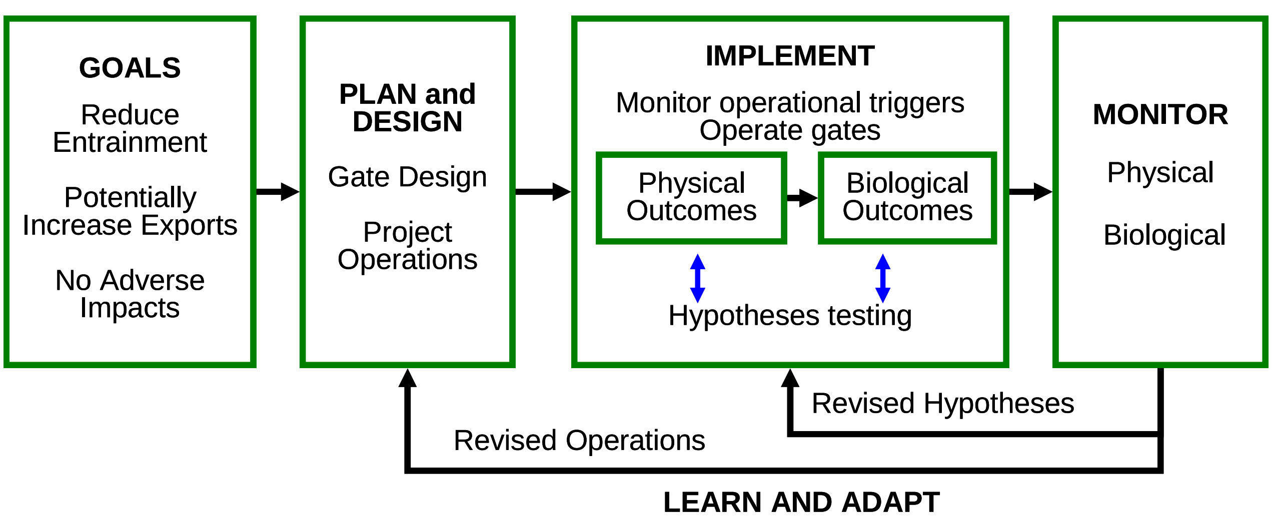

Figure 2. Adaptive management framework.

MONITORING FRAMEWORK

The 2-Gates Project is by design a limited-term demonstration project proposed for up to a five year trial period. Integral to the Project is a comprehensive monitoring and special studies program that serves multiple roles:

- To provide information for efficient Project gate operation decisions.
- To provide data to test hypotheses and which should reduce uncertainties regarding delta smelt responses to Project gate operations behavior, preferred habitat and life histories.
- To provide data to allow verification and testing of the models for future evaluation of operational changes.
- To provide data on the changes in flow, turbidity and other variables to evaluate the effects of the Project operations.
- To provide data to evaluate potential Project effects on other species of interest (e.g., predation risk at gate structures, movement of salmonids and sturgeon).
- To provide guidance for adaptive modifications of project operations and structures.

This Project summary document also focuses on special studies (and associated monitoring) required to test the physical process and delta smelt response concepts underlying project design (Appendices D and E).

In order to understand the effects of 2-Gates Project operations on hydrodynamic processes, a network of fixed-site sampling stations would be placed at key locations throughout the Delta (Appendix E). These stations either coincide with or will augment the network of existing Delta monitoring stations (Appendix C of the BA). These stations would monitor time-histories of various constituents such as temperature, salt, turbidity, and chlorophyll (Chl-a) at these locations, but would also measure the flux (or load) of these constituents. By co-locating constituent and discharge measurements and making these flux calculations, information will be gained as to how constituents vary in time at key locations in response to 2-Gate operations, and a record will be gained of how 2-Gates operations alter exchanges between regions in the Delta through these key channels.

These above special studies will be part of a larger monitoring and special studies program intended to provide a comprehensive picture of Project effects and effectiveness, particularly in regard to possible impacts on other listed species (Appendix C of the BA). This larger program is currently being developed in collaboration with regulatory agency representatives (e.g. NMFS and USFWS) and system monitoring entities, such as the Interagency Ecological Program (IEP). We recognize the sensitivity of expanding biological sampling in the Delta because of associated additional 'Take' issues for listed species. The Bureau of Reclamation and Department of Water Resources have been collaborating on the development of a "trawl-cam", a trawl mounted camera to harmlessly identify, measure and count fish as they pass out the cod end of a trawl. Successful development of such a non-destructive sampling technique would provide the ability to expand sampling while not increasing take of listed species. The system is ready for field testing this spring and will be incorporated into the monitoring program for the 2-Gates project as appropriate. It is expected that this comprehensive monitoring program will include:

- Identification of key potential Project impacts on other species that will be addressed by the Monitoring Program.
- Expansion of acoustic tag based investigations of the survival and pathways of juvenile salmon emigrating through the Delta to address occurrence and survival in areas influenced by the Project.
- Expansion of the principal existing adult delta smelt abundance and distribution monitoring effort, IEP's Spring Kodiak Trawl Survey, to cover the full season of Project adult operations and to intensify sampling in the area of the Delta affected by the Project.
- Temporal and geographical intensification of the principal juvenile delta smelt abundance and distribution monitoring effort, IEP's 20mm Survey, to better assess juvenile smelt responses to Project operations.
- New large-fish acoustic camera monitoring at gate locations to assess gate effects on adult sturgeon and salmon migration, and to assess the abundance and behavior of fish predators in the vicinity of the gates.
- Compilation of data from all relevant existing, expanded, and new monitoring programs, such that it is easily available for use by Project staff and collaborators.
- Establishment of data synthesis and information dissemination infrastructures to feed adaptive management decision making regarding Project operations. It is expected that existing decision making bodies, such as the Smelt Working Group and Water Operations Management Team will be the principle recipients of monitoring information related to the Project.

Because the Delta is complex and always changing, controlled experiments are generally not possible. It is the intent   to use the full body of information gathered through hydrodynamic modeling, and Project monitoring, special studies and field testing programs to draw inferences and conclusions about Project effects and effectiveness and expand our knowledge about how the Delta works.

Conceptual Foundation

The 2-Gates Project design and operations are based on our conceptual understanding of patterns and relationships of Delta hydrodynamics, fluxes in water quality parameters, delta smelt life cycle and behavioral responses to flow and water quality cues at different life stages, and entrainment at the export facilities.

ENTRAINMENT OF ADULT DELTA SMELT

Entrainment in water diversions and exports has been highlighted as one of several factors in the decline of delta smelt (FWS 2008)[1]. Large numbers of fish including delta smelt are entrained at the CVP and SWP export facilities, as indicated by salvage numbers (Brown et al. 1996). Delta smelt occur in salvage in December-March as adults, and May-June as juveniles (>20 mm) (Kimmerer 2008). Substantial numbers of larvae are presumed entrained as well (Bennett 2005, Kimmerer 2008), although levels of larval entrainment are unknown because the fish screening facilities cannot effectively sample fish smaller than 20mm (Baxter et al. 2008). The direct population-level effects of entrainment are difficult to determine, however (Bennett 2005, Manly and Chotkowski 2006, Kimmerer 2008).

Entrainment risk for delta smelt depends on their geographic distribution, with the greatest risk being in close proximity to the south Delta and water export facilities (Kimmerer 2008). The movement and distribution of adult delta smelt is affected by a variety of factors. These include Delta inflow, tidal flows, pumping at CVP and SWP export facilities, complex channel configurations, and connections along with salinity, temperature, and turbidity gradients (Grimaldo et al. in press). The southward movement of water influenced by pumping at the CVP and SWP water export facilities, increases vulnerability to entrainment (FWS 2008). Hydrodynamic change has been indexed using net flows through Old and Middle Rivers, which integrate changes in inflow, exports, and barrier operations (Arthur et al. 1996, Monsen et al. 2007). Net or residual flow refers to the calculated flow when the effects of the tide are mathematically removed. An initial statistical analysis revealed that there was a significant inverse relationship between net Old and Middle River flow and winter salvage of delta smelt at the SWP and CVP (P. Smith 2009). These analyses were subsequently updated and extended to other pelagic fishes (Grimaldo et al. in press). The general pattern is that Pelagic Organism Decline (POD) species salvage is low when Old and Middle Rivers flow are positive (Baxter et al. 2008). However, the biological mechanisms for these patterns of relationships have not been well understood. This test intends to improve the understanding of underlying smelt behavior.

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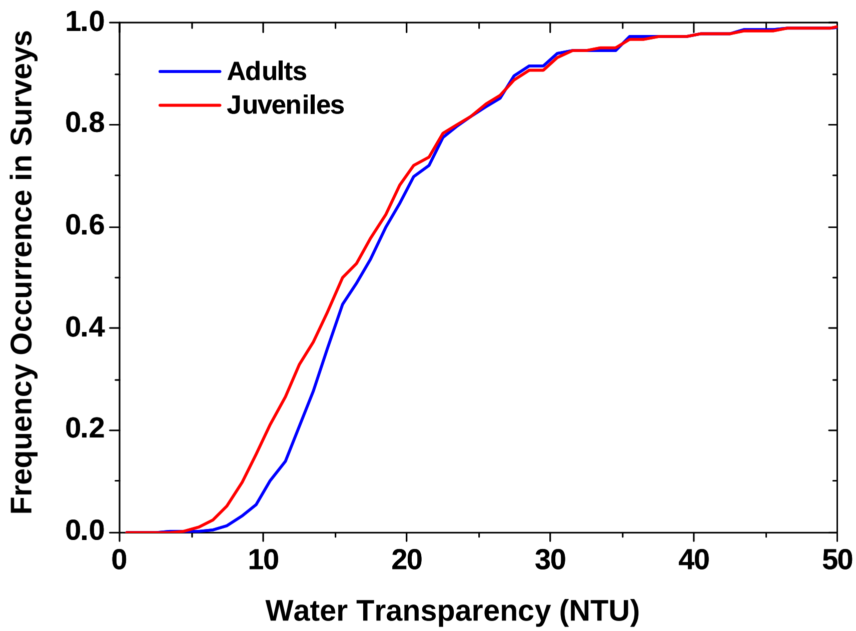
[1] Although it is beyond the scope of this Project, it is worth noting that other factors, alone or in combination, likely contribute to the decline of delta smelt. Abundances of delta smelt and several other pelagic species have declined significantly since 2000 (Sommer et al. 2007, Feyrer et al. 2007). The Pelagic Organism Decline (POD) outlined several possible mechanisms including: (1) prior fish abundance, which posits that continued low abundance of adults leads to reduced juvenile production (i.e., stock-recruit effects); (2) habitat, which posits that estuarine water quality variables, disease, and toxic algal blooms in the estuary affect survival and reproduction; (3) top-down effects, which posits that predation and water project entrainment affect mortality rates; and (4) bottom-up effects, which posits that food web interactions affect survival and reproduction (Sommer et al. 2007, Baxter et al. 2008).

The current regulatory framework to protect delta smelt is focused largely on statistically based flow objectives, specifically the reduction of exports in order to restrict negative OMR flows (FWS 2008, NMFS 2009). However, other factors may influence delta smelt distribution and movement, such as turbidity. Understanding the relationships among hydrodynamics, water quality and delta smelt behavior may reveal another mechanism for managing entrainment loss (Grimaldo et al. in press).

TURBIDITY RELATIONSHIPS

Recent evidence suggests low water transparency is a key characteristic of delta smelt habitat (Bennett 2005, Feyrer et al. 2007, and Nobriga et al. 2008). Water transparency is an important predictor of occurrence for delta smelt (Figure 3). This relationship has been observed for adults (Spring Kodiak Trawl data, Bennett 2009) and juveniles (20 mm survey, Bennett 2009; Fall Midwater Trawl, Feyrer et al. 2007). The mechanisms causing the negative associations between water clarity and delta smelt occurrences are unknown. One hypothesis is that turbidity may function as a trigger for upstream migration by adult delta smelt (Grimaldo et al. in press). Another hypothesis, based on studies at the Skinner Facility delta smelt hatchery, is that turbidity is necessary to enable larval smelt to detect their food (Joan Lindberg, pers. comm., Nobriga et al. 2008) hypothesized that higher water clarity increases predation risk for delta smelt and other fishes typically associated with turbid water. The last two hypotheses, however, do not address the correlation between hydrodynamics, turbidity and salvage. The predation hypothesis will not be studied by this Project, but it is under consideration by the POD studies (Baxter et al. 2008). The 2-Gates Project focuses on the correlation between turbidity, flows, and delta smelt distribution.



NOTE: The water transparency values (i.e. turbidity) were derived from Secchi depth readings from DWR EMP data collected at Chipps Island (1986-1999) and converted to turbidity by a nonlinear regression equation.

Figure 3. Relationship between Occurrence of Delta Smelt and Turbidity and Cumulative Frequency of Capture.

Upstream migration of pre-spawning adults appears to be triggered by abrupt changes in flow and turbidity associated with the first large precipitation event of the season in the basin ("first flush") results in abrupt increases in inflow and turbidity (Grimaldo et al. in press). Review of salvage trends found a correlation in several years between elevated turbidity, high exports, and increased salvage (FWS 2008) (Figure 4). When exports are high, net Old and Middle River flows can become reversed and flow south toward the facilities (i.e. negative OMR flows). Daily salvage of delta smelt at the export facilities is correlated with negative OMR flows (Kimmerer 2008).

It appears that turbidity in excess of 12-15 NTU is correlated with and may be a functional cue for the annual spawning migration by delta smelt from Suisun Bay to the Delta. We hypothesize that the distribution pattern of turbidity will influence the distribution of pre-spawning adult delta smelt in the central and western Delta. The adult distribution presumably may affect the location of spawning and the spatial distribution of their progeny. This would affect the entrainment risk of larvae and juveniles in the Delta until they move downstream to rearing habitat near Suisun Bay. Modeling of the hatching and mortality rates of the eggs and larvae from various regions within the Delta is being conducted by Gross and McWilliams (Bay Modeling) and Grimaldo (USBR.)

The location and structure of the turbidity field is affected by freshwater inflow, tidal flows and other Delta hydrodynamics, as revealed by recent hydrodynamic modeling of turbidity and flow conditions with and without 2-Gates Project operations (Appendix B). During high river flow periods, turbidity enters the western Delta from the Sacramento River and the central Delta via Georgiana Slough, and then enters the south Delta through Old River and Middle Rivers. Inflow from the San Joaquin River also contributes a pulse of turbidity, although the timing typically lags from the Sacramento River. When these two water bodies meet, they form a turbidity "bridge" from the central and west Delta to the south Delta (Figure 5 - Historic Condition). This continuous high turbidity zone allows smelt to move south toward the pumps. This pattern is illustrated in modeling of historic conditions and conditions under OCAP and OCAP with 2-Gates (Figures 5 and 6). Under historic conditions, turbidity levels exceed 15 NTU throughout the central and south Delta (Figure 5). High turbidity conditions (>35 NTU) exist continuously along the Old River channel (approximately 17 miles) from Franks Tract in the central Delta to the export intake at Clifton Court Forebay in the south Delta (Figure 6).

Water management actions (operation of the SWP and CVP export pumps) consistent with the OCAP RPA actions (FWS 2008) prevent or delay the "turbidity bridge" from forming in the south Delta channels by reducing negative OMR flows. Hydrodynamic modelings of turbidity distributions under OMR flow requirements indicates a reduction in turbidity in the central Delta (Figure 5) and along the Old River channel (Figure 6), although levels may still be above 15 NTU. The proposed gates, when operated in conjunction with OMR flow requirements, may provide greater control and more flexibility in keeping turbidity away from the pumps (Figures 5 and 6). A low turbidity region (< 15 NTU) is maintained for approximately 6 miles of Old River with gate operations in conjunction with OMR flow requirements (Figure 6).

Thus, entrainment reduction may be accomplished by controlling the distribution and continuity of turbidity and salinity conditions that appear to be a component of pre-spawning, adult delta smelt habitat. Preliminary results from the newly developed adult delta smelt behavioral model applications (Appendix B) suggest that the distribution and density of adults could be modified to reduce the potential for entrainment at the CVP and SWP facilities, in concert with pumping restrictions (FWS 2008) and the Project operations of the gates (Figure 5). Keeping pre-spawning adult delta smelt substantially out of the south Delta may also reduce potential entrainment of their progeny (larval and juvenile life stages). Questions have been posed whether a larger portion of the population may spawn in the north Delta. The adult model is currently undergoing improvements to better simulate the distributions of adults in the north Delta region. Inferences regarding the presence of spawning in this region would be a focus of the Project monitoring program.

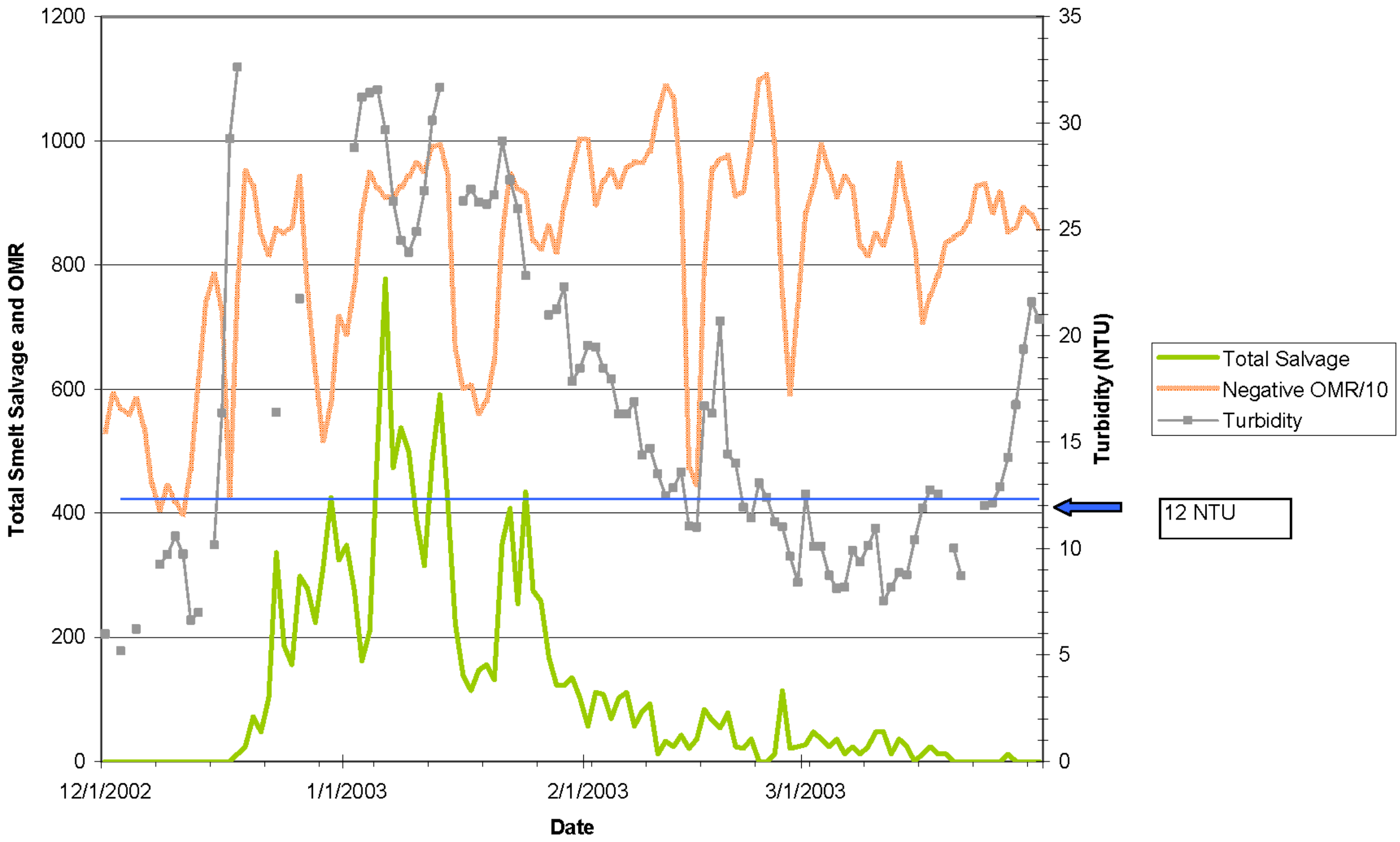


Figure 4. **Relationship between Turbidity, Old and Middle River Flows, and Ddelta Smelt Salvage.**

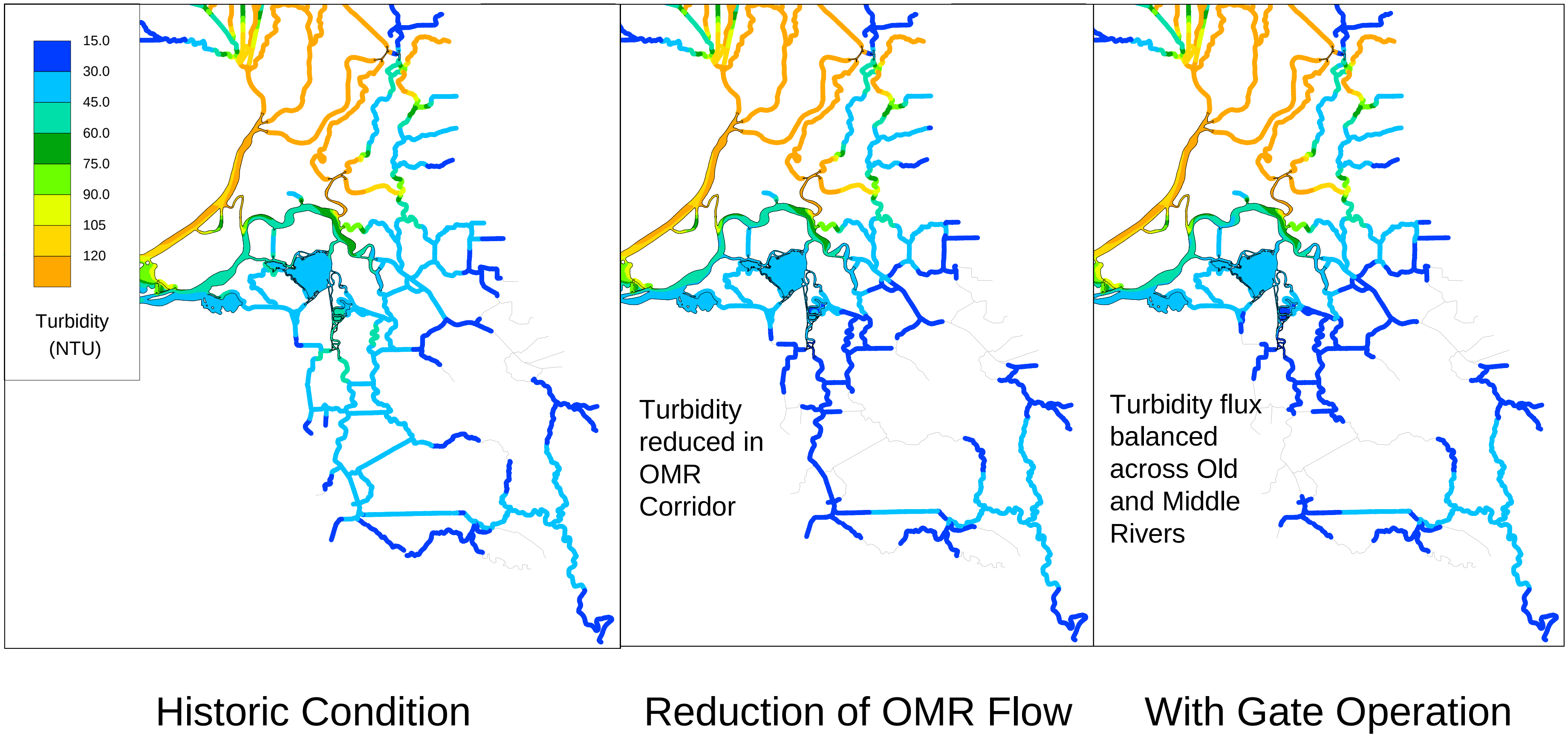


Figure 5. Operation of 2-Gates Project to Reduce Adult Delta Smelt Entrainment by Balancing Turbidity Flux along Old and Middle Rivers.

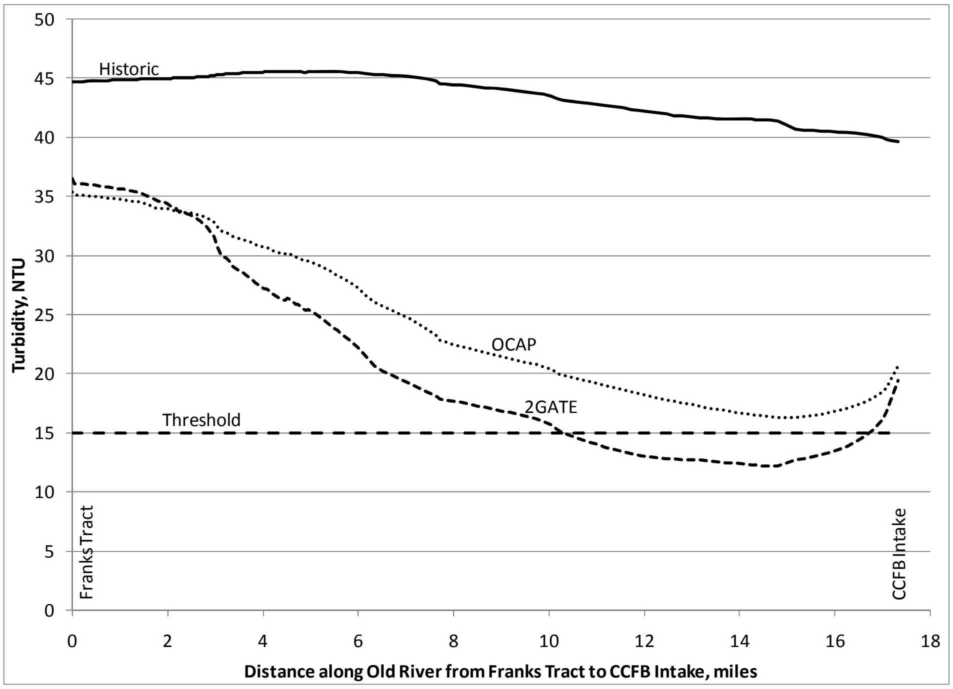
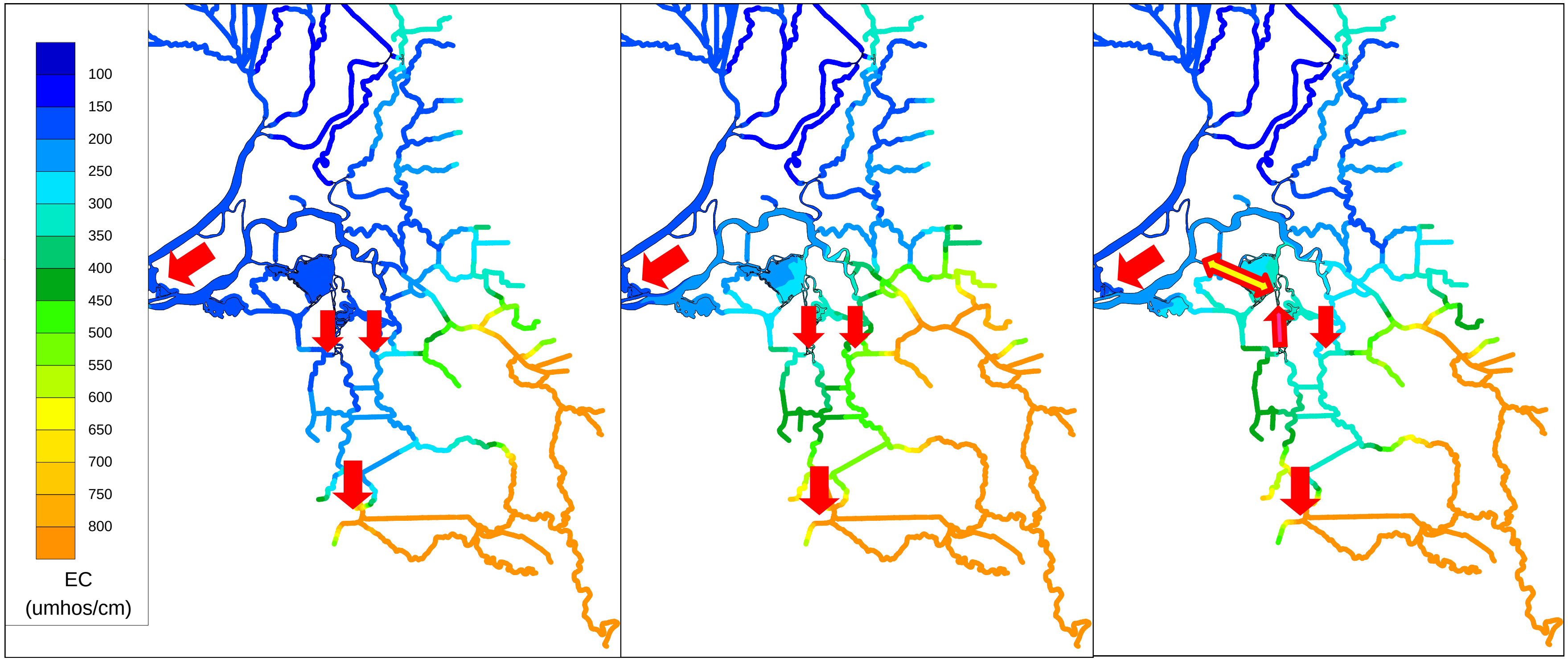


Figure 6. Longitudinal Profile of Modeled Turbidity along Old River from Franks Tract to Clifton Court Forebay.

DISPERSIVE MIXING

The gates may also be operated to enhance the transport of larval and juvenile delta smelt and organic carbon towards the western Delta and to reduce salinities at the export facilities. Larval delta smelt presumably drift with the predominant tidal currents, perhaps exercising some control through vertical migrations in the water column (Bennett 2005). They move downstream until they reach favorable rearing habitat, typically in the Suisun Bay region. Hydrodynamic modeling suggests that opening the gates on ebb tides can enhance mixing of water in the central Delta and can disperse flows seaward toward the western Delta (Figure 7). This has the potential to benefit delta smelt by (1) dispersing larvae and juveniles which are hatched in the central Delta away from the export pumps, thereby reducing entrainment risk of those fish, and (2) enhancing transport of central Delta juveniles westward toward rearing habitat near Suisun Bay. Particle tracking modeling of different water management scenarios suggest that entrainment of juveniles could be potentially reduced except for a very small percentage of those fish that hatch in the Mokelumne Rivers, Georgiana Slough or on the Sacramento River north of the Georgiana Slough confluence (Figure 8).



Historic Condition

Reduction of OMR Flow

With "Open on Ebb" Gate Operation

Figure 7. Operation of 2-Gates Project to Reduce Larval/Juvenile Delta Smelt Entrainment.

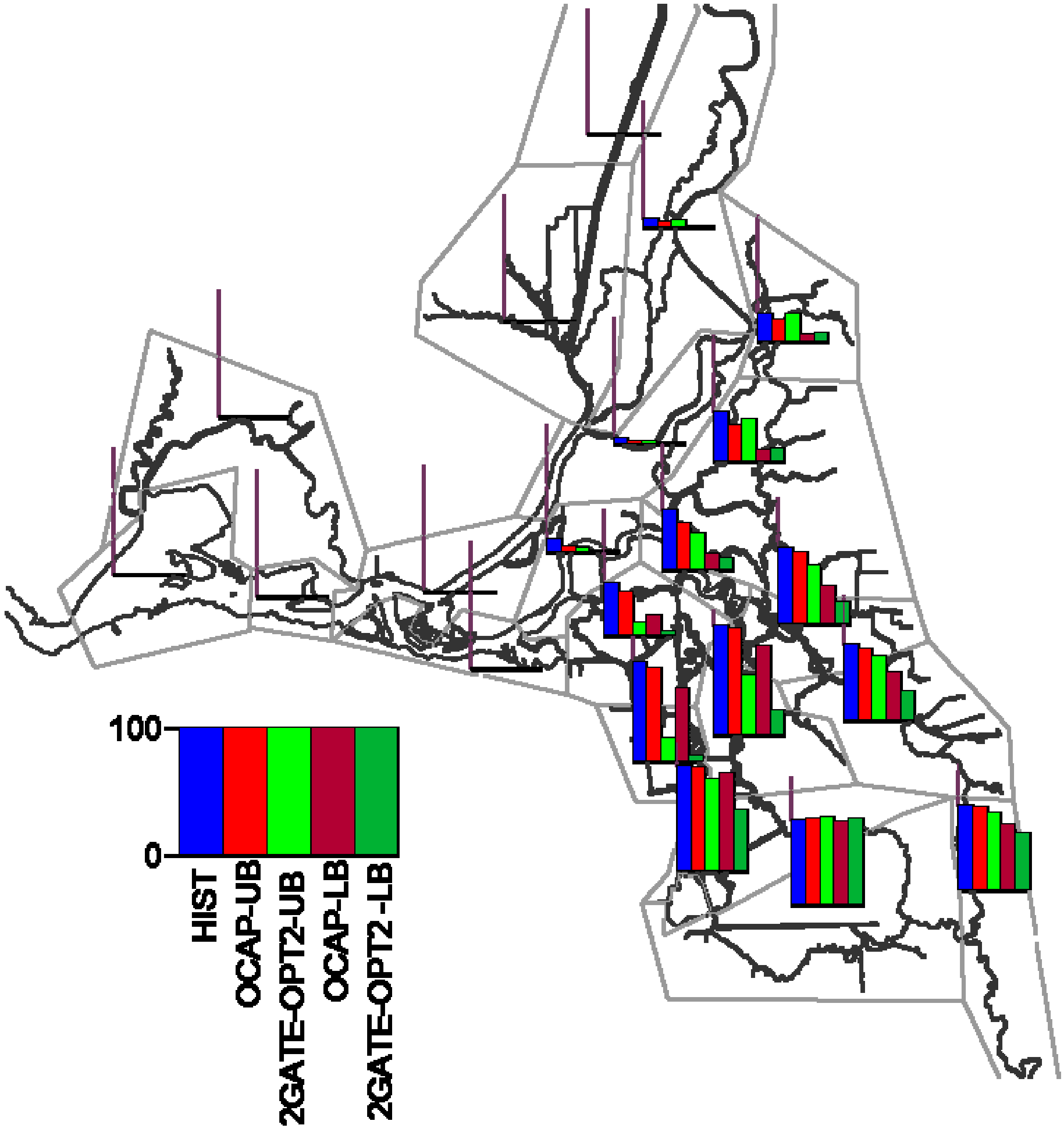


Figure 8. Percent of Particles Entrained at CVP+SWP by Region during the Modeled Period.

Finally, this dispersive mixing process could also be used to improve habitat in the Sacramento-San Joaquin confluence area by facilitating westward transport of nutrients and plankton originating in the upper San Joaquin River and southern Delta. The POD studies have hypothesized that "bottom up" factors, such as the quality and availability of food, may have important consequences for pelagic fishes including delta smelt. Low and declining primary productivity in the estuary is likely a principal cause for the long-term pattern of relatively low and declining biomass of pelagic fishes (Baxter et al. 2008). There has been a significant long-term decline in phytoplankton biomass (chlorophyll *a*) and primary productivity to very low levels in the Suisun Bay region and the lower Delta (Jassby et al 2002). Mueller-Solger et al. (2006) concluded that areas rich in high-quality phytoplankton and other nutritious food sources such as the southern Delta and small tidal marsh sloughs may be critical "source areas" for important Delta smelt prey organisms such as *Pseudodiaptomus forbesi* and *Eurytemora affinis* (Bennett 2005). This is consistent with results by Durand et al. (unpublished data in Baxter et al. 2008) that showed that transport from upstream was essential for maintaining the *P. forbesi* population in Suisun Bay.

CONCEPTUAL MODEL

Based on the current state of Delta science and our focused hydrodynamic modeling, we developed a simplified conceptual model to present the Project's chain of logic (Figure 9).

Our premise is that OMR flows are affected by several factors, including gate operations. OMR flows are expected to affect physical factors, such as local hydrodynamics and turbidity flux. These changes are in turn expected to affect the movement of adult smelt, their distribution, and consequently the distribution of their offspring. The risk of entrainment is increased if delta smelt are located in the south Delta in close proximity to the export facilities and where habitat conditions may be less favorable for juvenile rearing.

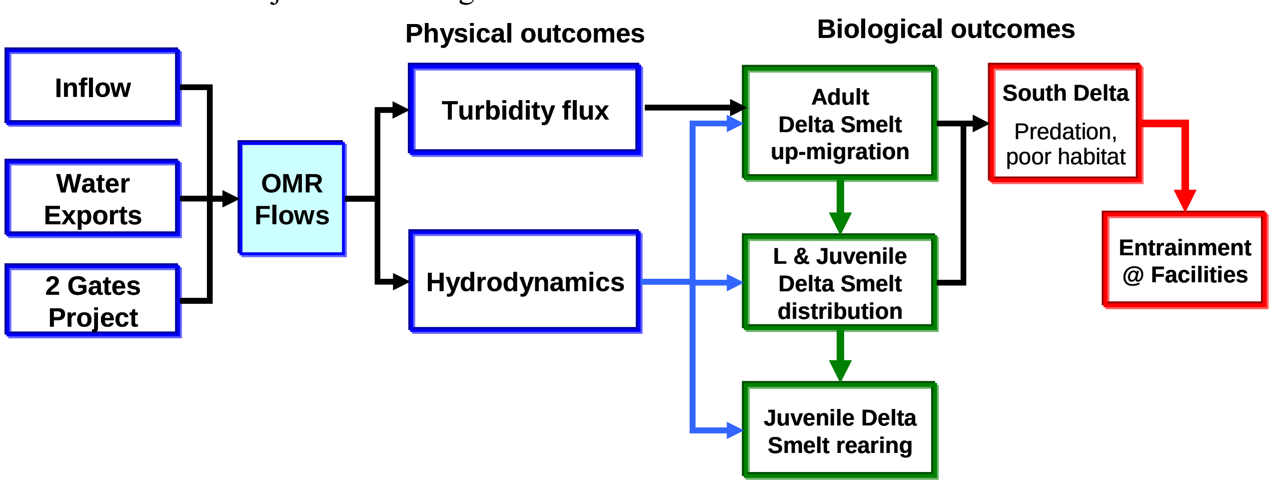


Figure 9. Conceptual Model of 2-Gates Project Inputs and Outcomes.

Key Questions & Hypothesis Testing

The Project is designed as a five-year demonstration project to evaluate the effectiveness of operable gate structures in managing Old and Middle River flows, turbidity and entrainment; and to test hypotheses of relationships among flows, turbidity levels and delta smelt distribution.

Hydrodynamic processes have been identified as important drivers affecting delta smelt habitat, movement, distribution, and vulnerability to entrainment by the export facilities (Bennett 2005, Grimaldo et al. 2007, Kimmerer 2008, and FWS 2008). The Project includes two life-stage-specific sets of operations to protect pre-spawning adults and juveniles. The key questions underlying the Project are:

- Can the Project reduce pre-spawning adult delta smelt entrainment in the CVP and SWP export facilities by maintaining a zone of low turbidity between the export facilities and the central and western Delta?
- Can the Project reduce juvenile delta smelt entrainment in the facilities by enhancing dispersive mixing to transport them from the south and central Delta into the western Delta?

The following sections present several generally-stated hypotheses regarding physical outcomes of gate operations and biological response of delta smelt (Table 1). These hypotheses are designed to test specific questions and underlying assumptions, refine understanding of processes that influence entrainment of delta smelt, and evaluate Project performance. This knowledge will be used to refine the Project design and operation to protect delta smelt and to guide regulatory decision-making.

Assessment of the 2-Gates Project provides a unique opportunity to gain insights into Delta processes and point the way towards follow-up investigations. However, there are significant challenges in attempting to conduct a quantitative, testable program in a natural, uncontrolled "experiment." The Delta is a complex environment and is subject to substantial fluctuations on daily, seasonal, annual, and multi-year time scales that are not necessarily predictable in spatial, magnitude, duration, or directional scales. In addition to these sources of variation, which may be derived by natural and/or anthropogenic forces, the assessment program may be influenced by the assessment program itself. For example, low densities of delta smelt may result in small sample sizes and reduced statistical power. The ability to conduct sampling may be constrained by endangered species take limits or other logistical constraints. Other factors such as Delta hydrology, temperature regimes, or predation may obscure the magnitude of project effects and make it impractical to obtain sufficient data to tease out the relative weights of the effects.

As a result, traditional controlled experiments are generally not possible in the Delta. Our experimental design recognizes these challenges. For example, the principles of the BACI (Before-After-Control-Impact) design are applied to reduce environmental variability between treatments. Another approach is to explicitly measure confidence intervals. These approaches will be applied as needed in specific studies used to test hypotheses. Some of the inferences or conclusions will be subject to substantial variability and uncertainty. This will undoubtedly require additional study and refinement of the monitoring program and modeling.

Table 1. Hypotheses/Questions for the proposed 2-Gates Fish Protection Demonstration Project.

No.	Hypotheses and Questions	Metrics [1]	Data sources	Test
Balanced Flows and Turbidity				
1	2-Gates Project operations can control net flows in Old River to achieve a predictable balance of flows in both Old and Middle Rivers.	▪ Flows in Old and Middle Rivers	▪ Existing and new flow monitoring stations. ▪ RMA modeled flows [2].	▪ A BACI experiment using modeled flows: test time series of flows with and without 2-Gates operations. [3] ▪ Compare observed flows to those predicted by the RMA model.
2	2-Gates Project operations, can balance net flows between Old and Middle rivers, as indicated in 1, to maintain a low turbidity region in Old and Middle Rivers.	▪ Flows in Old and Middle Rivers ▪ Turbidity (observed) down Old and Middle Rivers and into Franks Tract and lower San Joaquin River. ▪ Model results for flows and turbidity from forecasting and from concurrent conditions.	▪ Existing and new flow monitoring stations. ▪ Existing and new water quality stations (turbidity, EC, temperature and chlorophyll a). ▪ RMA modeled flows and turbidities [2].	▪ BACI experiment of model: test time series of flows and turbidities with and without gate operations. [3] ▪ Compare observed turbidity fluxes to those predicted by the RMA model.
Delta Smelt Migration and Salvage				
3	Migration of pre-spawning adult delta smelt from the Suisun Bay into the Delta and freshwater habitats occurs when initial winter storm events increase Sacramento River turbidity in the Delta to above a threshold of 12-15 NTU.	▪ Storm event (1st of season) ▪ Delta inflow ▪ Sacramento River flows ▪ Turbidity ▪ Delta smelt catch at fixed stations, one each in the Sacramento and San Joaquin rivers.	▪ Existing and new flow monitoring sites. ▪ New turbidity, EC and water temperature stations. ▪ Daytime fish catches in a stationary Kodiak or Midwater trawl over a ~12-hr tide cycle (Appendix D).	▪ Time series at fixed sites. Single field event monitored over tidal cycle.

1. Additional discussions are planned at the science panel.
2. RMA hydrodynamic model will run trials run over 1-2 weeks with controllable and stable net flows and exports. Test on same tide phase for both. Neap and spring >=twice each, learning as we go. First measure with gates open, then a few days with the gates operating (closed for all or some portion of 24 hours). This is not a pulse flow test.
3. Test is for no difference in mean flow for model runs with gates open and a difference when Project is operating, with multiple model runs. Do mean observed flows fall in range of predicted net flows, i.e., predictions are correct? Assume that the distribution of random variation under historic conditions applies to the test conditions. Use appropriate tests taking into account autocorrelation if necessary.

Table 1. Hypotheses/Questions for the proposed 2-Gates Fish Protection Demonstration Project continued.

No.	Hypotheses and Questions	Metrics [1]	Data sources	Test
Balanced Flows and Turbidity				
4	Maintaining a low turbidity region in Old and Middle Rivers reduces adult delta smelt salvage.[2]	▪ Turbidity ▪ Observed Salvage ▪ Model results for salvage	▪ Existing and new flow stations ▪ Existing and new water quality stations. ▪ Vessel-based turbidity monitoring down the Old and Middle Rivers ▪ Salvage	▪ A BACI experiment using modeled flows, turbidity and salvage: test time series of flows, turbidity and salvage with and without 2-Gates Project operations. ▪ Compare observed flows, turbidity and salvage to those predicted by the RMA model.
Dispersive Mixing				
5	Open-on-ebb operations increase dispersive mixing between the south-central Delta and lower San Joaquin River through Franks Tract-False River.	▪ Net flows in Old and Middle Rivers ▪ Calculate salt flux decomposition in False River west of Franks Tract or possibly measure bromide time series (Appendix E) ▪ Salinity and salts gradients from OR –FT-FR-SJR. ▪ Fingerprinting estimates based on bromide time series.	▪ Existing and new flow monitoring stations. ▪ Additional field data to fingerprint water source (e.g. bromide sensor)	▪ A BACI experiment using modeled flows: test time series of flows and salinity with and without 2-Gates Project operations. [3] ▪ Compare observed flow and salinity values with those predicted by the RMA model.

ADULT DELTA SMELT PROTECTION

Concept

Pre-spawning adult delta smelt migrate upstream from Suisun Bay into the Delta when initial storm events increase Sacramento River turbidity in the Delta. Recent study (Grimaldo et al. in press) suggests that turbidity plumes associated with the Sacramento River inflow are a likely trigger for upstream movement into the western Delta, including the lower San Joaquin River. If these initial plumes expand from the western Delta into the Old and Middle River corridor, adult delta smelt may track these turbidity cues southward to the pumps, resulting in entrainment losses.

Entrainment of adult delta smelt at the export facilities is correlated with negative OMR flows and high turbidity (Kimmerer 2008, Grimaldo et al. in press, FWS 2008). The relationship of flow and turbidity can be quantified simply as the turbidity flux (Tf) or the product of turbidity, C, and the discharge (or mass flux) in Old and Middle Rivers (Q: Tf=QC). Recent modeling results (Appendices B and C) suggest that the total turbidity flux at the facilities can be minimized by balancing the turbidity flux between Old and Middle Rivers (Figure 7).

Based on these data, it may be possible to reduce entrainment at the export facilities by manipulating flows and turbidity. The RMA models predict that the 2-Gates Project can establish a low turbidity zone in Old and Middle Rivers (Figures 6 and 7) that could, in coordination with less negative OMR flows, reduce entrainment of adult delta smelt. This would involve both (1) strategically-timed reduction of exports to reduce negative OMR flows, and (2) operation of the 2-Gates Project to balance the turbidity flux between the Old and Middle Rivers.

Balanced Flows and Turbidity

Hypotheses

Balanced flow and turbidity hypotheses have been developed with regard to the principle mechanisms influencing adult delta smelt movement. The ability to influence this movement further away from and less at risk of export facilities is expected to influence the regions of spawning and distribution of larva and juvenile delta smelt. Two hypotheses have been developed regarding flow and turbidity effects of gate operations (Table 1):

1. 2-Gates Project operations, coordinated with allowable changes in export levels, can control net flows in Old River to achieve a predictable balance of flows in both Old and Middle Rivers.

2. 2-Gates Project operations, coordinated with allowable changes in export levels, can balance net flows between Old and Middle Rivers to maintain a low turbidity region in Old and Middle Rivers.

Experimental Design

Modeled flow and turbidity will be compared with and without gates operations with actual measured flow and turbidity distribution to evaluate the project's performance in balancing flows and maintaining a turbidity gap in Old and Middle Rivers.

A BACI (Before-After-Control-Impact) experimental design will be used to compare the RMA predictions of flow with and without 2-Gates Project operations. Conducting a true BACI designed field experiment is not possible in the Delta because there is no suitable control site. For the Impact conditions, the RMA model will be run for a period of time (e.g., a week) without the 2-Gates Project operations (the Before period), and then for a similar period of time with 2-Gates Project operations (the After period). This will be repeated n times to obtain n sets of flow output time series differing because of the random variation in the RMA model. There will also be n runs of the RMA model for the Control conditions, where in this case the 2-Gates Project operations will not occur for both the Before and After period. This will provide n sets of flow output series, again differing because of the random variation in the RMA model. The value to be used for n will be determined based on trial runs of the RMA model with uncertainty incorporated. It needs to be a balance between having a sufficient number of runs to estimate mean predicted flow rates with reasonable accuracy and the need to keep the computing time to a reasonable level.

There are various analyses possible for the results of this BACI experiment. Initially a simple analysis involves calculating the mean flow on Day 1 of the Before period for the n Impact runs of the RMA model, and comparing this with the mean flow on the same day for the n Control runs of the RMA model. This comparison can be done for each day in the Before period and for each recorded flow variable. If the data are approximately normally distributed then a t-test can be used to compare the Impact and Control means, otherwise a randomization test can be used. Because the 2-Gates Project operations are not used in the Before period it should be found that only about 5% of the Impact – Control mean differences are significant at the 5% level. This then provides a test that the model results are behaving appropriately.

The mean flows on Day 1 in the After period can also be calculated for a flow variable from the n RMA model runs under Impact conditions, and the n runs under Control conditions. The difference between these means can then be tested for significance using a t-test or randomization test. In this case it is anticipated that most of the differences will be significant at the 5% level because the 2-Gates Project operations do change the flow rates in the RMA model. Confidence limits for the true mean differences can also be calculated to show the estimated effects of the 2-Gates Project operations and the level of sampling error involved with these estimated effects.

As well as the RMA model results there will be observed daily flow rates at sampling stations in the Old and Middle Rivers for the Before period (when the 2-Gates Project are not operating) and the After period (when the 2-Gates are operating) because the Impact Before and After conditions will be applied in the Delta as well as in the RMA model runs. These observed flow rates can be compared with the mean flow rates for the RMA Impact model runs to see whether the observed flow rates are within the range expected based on the n repeated runs of the model with random variation. If the differences between observed flows and mean model predicted flows are within the range expected from the random variation in the model then this confirms the validity of the model. If the observed flow rates are not within the ranges expected based on the random variation in the RMA model then the differences between the observed and predicted flows may suggest ways to improve the RMA model.

Adult Delta Smelt Migration and Salvage

Hypotheses

Hypotheses have been developed regarding the physical migration cues for pre-spawning adult delta smelt and the effectiveness of the project in reducing adult delta smelt entrainment (Table 1):

3. Migration of pre-spawning adult delta smelt from the Suisun Bay into the Delta and freshwater habitats occurs when initial winter storm events increase Sacramento River turbidity in the Delta to above a threshold of 12-15 NTU.

4. Maintaining a low turbidity region in Old and Middle Rivers reduces adult delta smelt salvage at the export facilities.

Experimental Design

Hypothesis 3 - Adult Migration and Turbidity

A set of integrated hydrodynamic and fish sampling studies are proposed to evaluate the role of water transparency (i.e. turbidity) in determining the timing and migration of delta smelt upstream into the Delta region (detailed in Appendix D). We propose to concurrently monitor hydrodynamic conditions and conduct fish sampling over a complete tidal cycle (about 12 h) at two locations (near Decker Island in the Sacramento River and near Jersey Point in the San Joaquin River). Fixed location sampling will let the tidal currents bring the fish and turbidity past us for the duration of a tidal excursion (approximately 8 miles each way), allowing us to effectively sample a total of 16 miles of river channel.

Sampling would occur in late December to early January at low Sacramento River discharge and then immediately following the first large precipitation event of the season in the basin (“first flush”). Previous work suggests that delta smelt typically arrive at the fish salvage facilities within about three days following a sharp increase in turbidity

(Grimaldo et al. in press), suggesting a rapid response by delta smelt to elevated turbidity. We anticipate that few, if any, delta smelt will be detected during the pre-turbid period, and more delta smelt will be detected as they move past our sampling location once a turbidity "bridge" forms between the low salinity zone and the western Delta (Appendix D).

The data from this experiment will be used to (1) tighten the linkage between observed delta smelt distributions (fall midwater trawl, Spring Kodiak Trawl, or salvage), (2) enhance, calibrate and verify the delta smelt behavior model described in Appendix D, and, (3) provide a real-time early warning system that would alert the water project operators to the onset of delta smelt migration into the central Delta.

Hypothesis 3 is supported if the migration of pre-spawning adults is observed to occur when an initial winter storm event increases the Sacramento River turbidity to above the stated threshold. This requires that there are few if any adult delta smelt observed in samples in the Delta before the storm event, but an increasing number after the storm event. If a sufficient number of adult delta smelt are observed a test for an impact of the storm event will be possible based on the time series of catches of the fish.

Hypothesis 4 - Adult Entrainment

We will compare modeled salvage with and without gates operations with actual observed salvage to evaluate the project's performance in reducing adult delta smelt entrainment. We would expect to observe no salvage if there is a turbidity gap (<12 NTU) in Old and Middle Rivers. There may be other outcomes depending on field conditions. For example, if there is (1) high turbidity measured at the export facilities due solely to high turbidity in San Joaquin River inflow to the Delta that is pulled across at Grant Line Canal, but (2) low turbidity at Franks Tract, then the turbidity gap is present and we would expect no salvage. If there is a sufficiently high San Joaquin River inflow that produces a strong turbidity gradient from the south Delta, the turbidity gap will not be maintained. This project is not designed to control flows originating from the San Joaquin side. Therefore, we would expect salvage to occur.

Testing hypothesis 4 follows the same BACI design procedure as for hypotheses 1 and 2. There will be n runs of the RMA model with a Before period with no 2-Gates Project operation, followed by an After period with 2-Gates Project operations. This gives n Impact runs. There will also be n control runs of the model with no 2-Gates Project operations in both the Before and After periods. Comparison between the daily modeled values for flow rates, turbidity and salvage should then show similar mean values for the Control and Impact runs in the Before period, but significantly different means are expected in the After period. Confidence limits for the mean differences in the After period then indicate the magnitude of the 2-Gates Project effects and the sampling errors in determining these effects. In addition the Impact conditions will apply in the Delta so that a comparison of the modeled mean flow, turbidity and salvage values with the observed values at sampling stations will indicate whether the model predictions are correct. If the observed values are within the range expected based on the RMA model including randomness then this will confirm the accuracy of the RMA model. If the observed values are outside the range expected with randomness in the RMA model then this may suggest how the RMA model can be improved.

Testing of hypothesis 4 may be inhibited by high variability in the salvage variable. Fish salvage at the CVP and SWP Delta fish screening facilities is often used as an index for entrainment at the CVP and SWP intakes. However, the relationship between entrainment and salvage can vary considerably over short periods of time due variations in pre-screen mortality (caused by variation in factors such as predator activity and Clifton Court Forebay habitat conditions) and screening efficiency (due to variation in export rates or fish size). Also, the number of delta smelt observed during salvage sampling may be very low. It may be possible to reduce the confidence limits around estimates of salvage by increasing the level of sampling during test periods or maintaining relatively steady water project operations (e.g. export rates and Forebay gate operations).

DISPERSIVE MIXING

Concept

The distribution of larval and juvenile delta smelt depends on spawning locality (distribution of spawning adults) and Delta hydrodynamics (FWS 1994). Adequate flows are necessary to transport larvae and juveniles downstream to productive rearing habitat in Suisun Bay and to prevent entrainment by the export facilities. Tidal operation of the 2-Gates Project may increase dispersive mixing of water in the central or southern Delta seaward toward the western Delta. This has the potential to (1) disperse larval/juvenile smelt spawned in the central and southern Delta away from the export pumps, thereby reducing entrainment risk, (2) enhance juvenile transport westward toward rearing habitat near Suisun Bay, and (3) enhance export of nutrients and phytoplankton to the west Delta. Preliminary modeling illustrates the tidal pumping through Franks Tract that could occur with Project operations (Figure 7).

The hypothesized dispersive mixing process could also be used to improve habitat in the Sacramento-San Joaquin river confluence area by facilitating westward transport of nutrients and organic carbon (e.g. phytoplankton and zooplankton) originating in the upper San Joaquin River and southern Delta. This expected effect would be confirmed with water quality parameters (e.g. chemical fingerprinting of water to differentiate San Joaquin River and Sacramento River waters within False River and the western Delta). Modeling results suggest that the Project would achieve greater reduction of cumulative entrainment of larval/juvenile delta smelt than OMR flow restrictions alone (Figure 8).

Hypothesis

We developed the following hypothesis to examine Project effects on a hydrodynamic process for juvenile delta smelt transport:

5. Opening the Old River gate on ebb-tide and closing it on flood creates net circulation downstream on Old River and upstream on Middle River that increases mixing between Franks Tract and western San Joaquin River.

Experimental Design:

The dispersive mixing hypothesis will be tested through a specific enhancement of water quality and hydrodynamics monitoring described in Appendix D. We intend to use changes in the salt (and perhaps *chlorophyll a* (Cl-a)) flux in False River to test the "dispersive mixing mechanism" behind 2-Gates Project operations designed to reduce entrainment of larval and juvenile delta smelt that are hatched in a broad region of the central and southern Delta. If 2-Gates Project operations do increase dispersive exchange of water (and hopefully larval and juvenile delta smelt) from the central and southern Delta into the western delta and salinities are elevated in the San Joaquin, then San Joaquin River salt could be used as a conservative tracer. If the "dispersive mixing mechanism" is working as planned, then an increase in dispersive flux in False River should be detected, which would be directed from Franks Tract into the western San Joaquin Delta – a direct measure of the effectiveness of 2-Gates Project operations in creating this transport mechanism. Moreover, if 2-Gates Project operations facilitate westward transport of organic carbon (e.g. phytoplankton) originating in the upper San Joaquin River and southern Delta, then an increase in Chl-a flux should be observed through False River (presuming it is not completely grazed down by the benthos). These are but a handful of examples of how fluxes will be used in this project to inform real time operations and evaluate performance.

The testing of hypothesis 5 again involves a BACI design. There will be n Impact runs of the RMA model with a Before period with no 2-Gates Project operations, followed by an After period with the 2-Gates Project operations. There will also be n Control runs of the model with no 2-Gates Project operations in either the Before of After period. Comparisons between daily mean values for flows and salinity should show that that these are similar for the Impact and Control conditions in the Before period but differ in the After period. The estimated mean differences with confidence limits then indicate the magnitude of the 2-Gates Project effects and the likely sampling error in the estimated effects. In addition because the impact conditions will be applied in the Delta a comparison between the observed daily values for river flows and salinity with the values observed at field stations will show whether the observed values are within the range expected from the RMA model with randomness. If the observed values are within the expected range then this will confirm the accuracy of the RMA model. If observed values are outside the range expected from the RMA model then this may indicate ways in which the RMA model can be improved.

Physical and Operational Elements

The 2-Gates Project is a five-year demonstration project designed to improve Delta water management operations while protecting delta smelt and other species in the Delta. The Project proposes to use two operable gates placed in the central Delta to allow greater control of the combined flows in Old and Middle Rivers in order to reduce entrainment of fish from the western and central Delta to the export facilities. This section briefly describes the basis for the project design and operations, the gate structures, gate operations, monitoring approach, and a framework for hypotheses testing, adaptation and decision-making.

PROJECT LOCATION

The Project includes two gate structures located on Old River and Connection Slough in the central Delta, approximately 13 and 16 miles northwest of Stockton, and 4.8 and 6.8 miles north and northwest of Discovery Bay, respectively. As shown on Figure 1, the Old River site is located on Old River between Holland Tract and Bacon Island, about 3 miles south of Franks Tract and about 1 mile north of the confluence of Old River and Rock Slough. The Connection Slough site is located about 3.5 miles southeast of Franks Tract between Mandeville Island and Bacon Island and between Middle River and Little Mandeville Island.

GATE STRUCTURES

The gate design consists of two 75-ft. steel-frame butterfly gates mounted on a steel barge. The gate structure would be floated to the site and ballasted into place on a prepared rock bed in the channel. The barge is held in place by rock fill placed upstream and downstream of the barge. The barge deck elevation will be about the same as the channel bed. The double butterfly gates are supported on center pivots to allow vessels to pass through the barrier with a 75-ft. clear opening. The gates will be operated by steel-frame members connecting to hydraulic cylinders and powered from the local power grid. Sheet pile dikes (walls) would extend from the barge-gate system to the channel levees. The gate top elevation will be +6.6-ft.   An operator would be on site 24-hours daily. Figure 10 shows a schematic view of the open gates.

Predatory fish and birds are known to congregate at structures. The 2-Gates Project design considered potential predation risks and incorporates measures to evaluate and reduce predation opportunities at the gate structures, as described more fully in the Monitoring Plan in Appendix C of the BA. Monitoring will be conducted to assess predation risk and appropriate response measures to reduce or eliminate predation would be taken with agency consultation during the operational phase (see Appendix C in the BA).

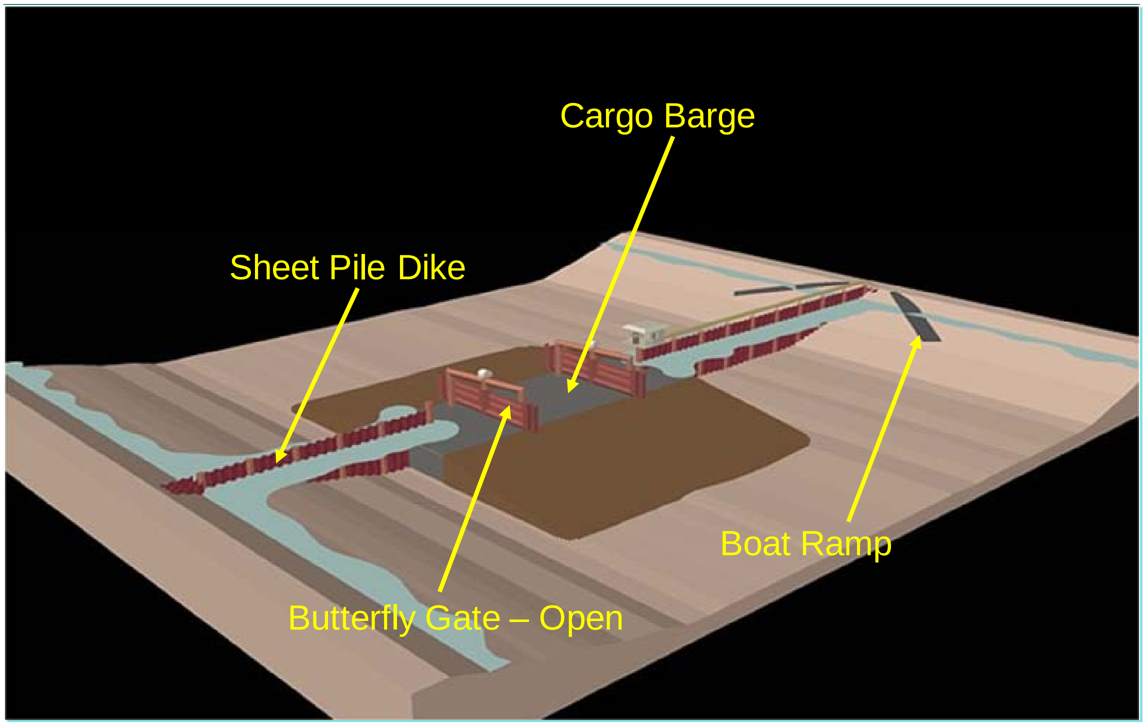


Figure 10. Conceptual View of the Old River Facilities.

PROJECT OPERATIONS

The initial concept for operating the Project was developed and refined using extensive hydrodynamic and delta smelt behavioral modeling (Appendix A). Initial Project operations would be adapted iteratively, based on monitoring and evaluation. Through this adaptive process, and as guided by the multi-parameter monitoring program, it is expected that progressively reduced entrainment of delta smelt will be achieved, along with potential water supply benefits. The circulation pattern resulting from the 2-Gates Project influences the distance that higher turbidity water travels upstream in Old and Middle Rivers (i.e. south toward the export facilities). The Project operation complements the FWS Biological Opinion flow conditions in the central Delta, but goes beyond just reducing negative flows by limiting the establishment of water quality conditions, including turbidity, thought to be a primary constituent element of pre-spawning delta smelt. It is hypothesized that the Project will enhance the isolation of delta smelt from water management operations at the CVP and SWP pumps by limiting the upstream movement of turbidity concentrations found to attract adult delta smelt in Old and Middle Rivers.

The control of water movement from the central Delta into the south Old and Middle Rivers is critical to the reduction of entrainment of delta smelt (and other pelagic species) by the export facilities. These water quality conditions (salinity and turbidity) are positively correlated with the onset of winter storm and runoff events on the Sacramento and San Joaquin rivers (Appendix C). Since these conditions can change rapidly, the Project includes a real-time data gathering and decision framework that evaluates the best course of action for particular delta smelt distributions, anadromous fish migrations, and hydrodynamic and water quality conditions.

Modeling Basis for Operations

To develop the initial operations plan, Resource Management Associates (RMA) developed and refined a series of hydrodynamic model analyses, to examine expected effects from different operations scenarios. These models are summarized below, with details provided in Appendix B.

Hydrodynamics and Turbidity Modeling

The models of the Delta utilize the RMA finite element models for surface waters. (Appendix B). The RMA models are a generalized hydrodynamic model that is used to compute two-dimensional depth-averaged velocity and water surface elevation (RMA2) and another model (RMA11) that is a generalized two-dimensional depth-averaged water quality model that computes a temporal and spatial description of water quality parameters. RMA11 uses stage and velocity results from RMA2. The Delta model extends from Martinez to the confluence of the American and Sacramento Rivers and to Vernalis on the San Joaquin River. Daily average flows in the model are applied for the Sacramento River, Yolo Bypass, San Joaquin River, Cosumnes River, Mokelumne River, and miscellaneous eastside flows which include Calaveras River and other minor flows. The model interpolates between the daily average flows at noon each day. Delta Islands Consumptive Use (DICU) values address channel depletions, infiltration, evaporation, and precipitation, as well as Delta island agricultural use. DICU values are applied on a monthly average basis and were derived from monthly DSM2 input values. Delta exports applied in the model include SWP, CVP, Contra Costa exports at Rock Slough and Old River intakes, and North Bay Aqueduct intake at Barker Slough. Dayflow and IEP database data are used to set daily average export flows for the CVP, North Bay Aqueduct and Contra Costa's exports.

RMA ran a set of hydrodynamic, EC, and Turbidity simulations to form the basis of the initial gate operations schedule. The modeling study evaluated how conditions change in the Delta under historical conditions, historical conditions operated under the OCAP RPAs and operated under OCAP RPAs with the Project. Historical simulations were run for the period between December and July for 1999-2000, 2002-2003, 2003-2004 and 2007-2008. These years were selected because they were the only ones with adequate data to support the analysis.

The hydrodynamic model will be further calibrated with field data from gate operations in the first year, using principles from the Before-After-Control-Impact (BACI) design (e.g. Green 1979, Stewart-Oaten and Bence 2001):

The Before-After-Control-Impact (BACI) design is often used to assess the effects of an environmental change made at a known point in time, and was called the optimal impact design by Green (1979). Typically, two similar sites are selected for comparison, with one being the treated site and one the control site. Both are observed for some time without any treatment being applied (the before phase). Then a change is applied to the treated site, and both sites are observed for a further period of time (the after phase). The assumption is that for some variable measured at both sites at regular time intervals (i.e., once per day) the observations in the before phase will show the general relationship between the two sites in the absence of any treatment being applied, and that if this relationship changes substantially after the treatment is applied then this change provides evidence of an effect of the treatment.

Conducting a true BACI designed field experiment is not possible in the Delta because it is not possible to establish a truly comparable control site. However, in the context of the 2-Gates Project the BACI design will apply with alternative sets of runs of the hydrodynamic model for the Delta. One set of n runs of the model will be made without the operation of the gates for a period of d_1 days (the before phase). The operation of the gates will then begin, and continue for a period of d_2 days (the after phase). Each run of the model will produce daily values for the variable of interest (e.g., the net Old and Middle River flow). These values will differ between runs because of the random variation applied within the hydrodynamic model. However, the results can be summarized by the daily means with estimated standard errors. These will then be the results for the treated condition.

Another set of n runs will be made for the control condition. In this case each run of the model will consist of d_1 days without the operation of the gates (the before phase), followed by a further d_2 days with the operation of the gates. Again the control condition results can be summarized by daily means for the variable of interest with estimated standard errors.

For this experimental design the daily means for the variable of interest should be very similar for the treated and control conditions in the before phase because neither had any gate operations. However, in the after phase the gates were operating for the control runs of the hydrodynamics model and therefore it is anticipated that the daily means will be significantly different for the control and treated conditions. This will then provide evidence of an effect of the gates.

After random variation has been added into the hydrodynamic model the number of runs (n) for the control and treated conditions with BACI experiments will be set to ensure that there is high power to detect an important gate effect. This will require trial runs of the model to determine the level of variation in the model output that results from the introduced randomness.

A simple analysis of the BACI experiment just involves comparing daily means for the control and treated conditions in the after period to see whether these are significantly different and to find confidence limits for the gate effects. More complicated analyses of all of the results together are also possible taking into account the autocorrelation in the daily time series of results (e.g. see Stewart-Oaten and Bence, 2001). These will be considered when more is known about the nature of the output from the hydrodynamic model with random variation included.

If the operation of the two gates used in the treated conditions for the hydrodynamic model is also used for the operation of the real gates then the extent to which the model represents reality can be checked. The daily means for the variable of interest are known for the control conditions from the model, together with the variation from n different runs of the model, first for d_1 days without the operation of the gates and then for d_2 days with the operation of the gates. For a perfect model the observed daily values for the variable of interest from the Delta will appear to be like one of the runs of the model. For a less than perfect model (as expected) there will be some systematic differences between the observed values and the predicted values from the model.

Delta Smelt Behavioral Modeling

Passive particle tracking techniques do not represent adult delta smelt well because these fish are sufficiently strong swimmers able to resist tidal flows by moving out of the current and into shoals or near the bed where velocities are low. Entrainment of adult delta smelt occurs during the period when the fish choose to move upstream for spawning. Periods of peak entrainment are correlated with high turbidity in the neighborhood of the exports resulting from storm flows.

Delta smelt distribution and entrainment was modeled with two distinct particle tracking techniques representing the adult life stage and the larval/juvenile life stages (detailed in Appendix B). RMA developed a particle behavior model to simulate the movement of pre-spawning adult delta smelt based on simulated distributions of salinity (represented as electrical conductivity, EC) and turbidity. Because turbidity is a key driver for the distribution of adult smelt, the optimum gate operation to minimize adult entrainment is based on controlling progress of the turbidity plumes from the Sacramento and San Joaquin Rivers and reducing the turbidity along Old and Middle Rivers downstream of the export facilities.

Larval and juvenile delta smelt are considered to be small enough to represent as passively transported particles. Initial evaluation of gate operations for minimizing larval and juvenile entrainment was performed by CH2M Hill. In that study, the DSM2-PTM (Delta Simulation Model II – Particle Tracking Model) was use to evaluate potential entrainment for smelt monitoring locations around the Delta. In this analysis a passive particle tracking methodology (developed by Dr. Edward Gross with Dr. Lenny Grimaldo (USBR) and Dr. Ted Sommer (DWR)) is used to represent the spatial and temporal distribution of larval and juvenile delta smelt, considering hatching rates, growth, and mortality. Hatching rates are derived through an automated tuning algorithm that develops a best fit estimate of regional hatching rates from the historic 20mm Trawl Surveys. Optimizing gate operations to minimize larval and juvenile entrainment involves minimizing advective and dispersive transport from regions of the Delta where fish densities are highest.

Both the adult and larval/juvenile particle tracking analyses utilize the RMA Bay-Delta Model for hydrodynamics and water quality simulation and the RMATRK particle tracking model.

These models will be calibrated and refined with data collected during Project operations. Currently, the adult delta smelt model provides a single estimate of in-Delta distribution and entrainment as function of time based on the hydrodynamic and water quality results from the RMA Bay-Delta Model for a particular set of boundary conditions and operations. The adult delta smelt particle tracking model utilizes the time dependent velocity field produced by RMA2 and the electrical conductivity (EC) and turbidity fields produced by RMA11.

In order to improve model accuracy, the uncertainties present will be carried in the hydrodynamic and water quality models through the adult delta smelt particle tracking simulations to estimate uncertainty bounds. Comparison of model results to historic conditions for specific calibration periods illustrates the accuracy with which the models can predict behavior of the physical system. A form of "bootstrapping" (Chernick 1999) can be used to take a single set of hydrodynamic and water quality modeling results and derives multiple realizations of the particle tracking model. This method uses differences between model results and observed data for the calibration periods to estimate confidence intervals. The behavior parameters of the adult delta smelt model will be treated as constants and will not contribute to the variation at this stage of modeling.

The general approach is as follows.

1. Process the computed and observed time series of stage, flow, EC, and turbidity to prepare discrete sets of deviations for velocity, EC, and turbidity which will be use in the bootstrapping procedure.

2. Revise the particle tracking model to read the sets of bootstrapping deviations and randomly apply the deviations to the base hydrodynamic and water quality results, by sampling them with replacement.

3. Revise the particle tracking model to run multiple realizations (on the order of 10-100) for each base set of hydrodynamic and water quality results defining an alternative, producing a distribution of results.

4. Evaluate the distribution of particle tracking results to identify the mean and confidence intervals for the in-Delta distribution and entrainment. Bootstrap percentile confidence intervals (Chernick, 1999, p. 53) will be used initially for this purpose.

REAL-TIME FORECAST MODELING

The following summary outlines the essential functions of a forecasting model to guide pre-emptive gate operations, using as a starting point the initial gate operations described here. This model is currently under development and will be operational when initial gate operations take place.

Effective real-time forecasting requires knowing initial water quality and flow conditions, acquiring and interpreting delta smelt survey and salvage data, operations forecasts, and timely agency interaction. Forecasts would utilize the most recent field observations of delta smelt distribution and density; and forecasted estimates of inflow, inflow water quality, and operations. For each forecast period, several simulations may be performed using alternative estimates of future conditions. An initial set of forecast simulations would be performed using best estimates of future operations provided by Reclamation and DWR system operators. Upon review of delta smelt distribution and entrainment estimates by the Smelt Working Group (SWG), a second set of forecast simulations may be performed with revised future operations with the objective of identifying operations that reduce expected delta smelt entrainment.

In real-time, an initial set of forecast simulations will be performed using best estimates of future operations provided by Reclamation and DWR system operators. Upon review of delta smelt distribution and entrainment estimates by the SWG, a second set of forecast simulations may be performed with revised future operations with the objective of identifying operations that reduce expected delta smelt entrainment.

The 2-Gates Project operations would be conducted in conjunction and coordination with both OCAP BOs OMR RPAs. Flow, salinity, turbidity, and particle forecasting simulations would be performed to forecast timing of the Old River and Connection Slough gate operations consistent with the FWS and NMFS OCAP RPAs. OMR flows restrictions would be achieved primarily through export curtailments.

Since the 2-Gates Project is being proposed as a temporary project aimed at reducing delta smelt entrainment, it is useful to describe an operating plan that is sufficiently flexible to adapt to real-time monitoring and predictive hydrodynamic, water quality, and delta smelt behavior modeling. DSM2 modeling results have shown that the operational effects of various measures of entrainment are strongly influenced by the initial distribution of delta smelt and relatively short duration adverse hydrodynamic conditions in winter and spring.

Initial Operations Framework

The Project is designed to be operated in conjunction and coordination with OMR flow restrictions in the FWS OCAP BO (FWS 2008). Further analyses are being performed to integrate operations consistent with the NMFS OCAP BO. This may include additional restrictions in gate operations in March and April. Currently, there are two operational scenarios, based on life-stage-specific objectives and season under the FWS OCAP BO (Table 2). The hydrodynamic and behavioral models were used to optimize the timing and duration of gate operations for each scenario. The specifics of initial operational scenarios in the first year are discussed below. Operations in subsequent years could be adjusted, based on monitoring data, to improve project operations effectiveness and to refine hypotheses.

Table 2. Initial operational scenarios for 2-Gates Fish Protection Demonstration Project.

Scenario	Season	Operational schedule	Notes
Pre-spawning Adult protection	Dec-March	Gates closed 1-2 hours daily	▪ Gates would be operated to balance flows and maintain a turbidity gap in Old and Middle Rivers. ▪ Operations triggered when turbidity ≥ 12 NTU at San Joaquin River at Jersey Point. ▪ This Period ends once water temperatures ≥ 12 degrees C.
Larvae and Juvenile Protection	March-April	Old River gate closed on flood tide (twice daily, up to 10 h total daily) and open on ebb and slack tides (~4 hours daily). Connection Slough gate closed except during slack tide (~4 hours daily).	▪ Gates would be operated to maximize dispersive mixing. ▪ Commence operational scenario once water temperatures ≥ 12 degrees C.
	April 16- May 15	Gates open at all times	▪ Gates would not be operated during the VAMP period
	May 16-June 30	Gates closed on flood tide (twice daily, up to 10 h total daily) and open on ebb and slack tides (~4 hours daily)	▪ Gates would be open during Memorial Day weekend. ▪ Cease gate operations June 30 or when Delta water temperatures ≥ 25 degrees C.
No project ops	July – Nov	Gates open at all times	▪ Gates would be open continuously to allow fish movement navigation.

Adult Delta Smelt (December through March)

To protect pre-spawning adult delta smelt as they migrate inland, the gates would be operated from December through March. The Old River and Connection Slough Gates would be operated when triggering turbidity concentrations ≥ 12 NTU begin to appear at San Joaquin River at Jersey Point.

Hydrodynamic modeling results indicate that the gates should be operated about an hour per day in a closed position, combined with flow balancing to manage the turbidity plume and adult delta smelt distributions. Behavioral modeling has shown that 2-Gates Project, in conjunction with OMR flow restrictions is effective in maintaining the turbid conditions linked to pre-spawning movement of delta smelt generally within the central Delta, thereby reducing the entrainment of delta smelt at the CVP and SWP pumps. These early actions may also control the initial distribution of larval and juvenile delta smelt in locations that reduce the probability of entrainment at the CVP and SWP export pumps.

These operations would be taken until water temperatures ≥ 12ºC ((3-station daily mean at Mossdale, Antioch and Rio Vista). This threshold signals a transition from adult to larvae/juvenile delta smelt management actions.

There are real-world limitations to successfully managing turbidity distribution in the Delta, including stochastic events of irregular recurrence. For example, turbidity associated with very large San Joaquin outflow may overwhelm the ability to maintain a low turbidity region in the Old and Middle River corridor. Also, when Delta outflows are high, adult delta smelt are located far west of the central Delta and entrainment vulnerability is low.

Larvae/Juvenile Delta Smelt (March through June)

To provide added protection to larvae/juvenile delta smelt, the gates would be operated to enhance dispersive mixing for downstream transport. Gate operations for larvae/juvenile smelt would take place from March through June except during the Vernalis Adaptive Management Plan (VAMP) period (April 16 – May 15), and the Memorial Day weekend when gates would remain open. The predominate mode of gate operations includes (1) the Old River gate closed about 10 hours per day on flood-tide and open about 14 hours per day on ebb-tides including slack-tides, and (2) the Connection Slough gate closed except during slack-tides.

The period of gate operations and OMR restrictions for larvae/juvenile delta smelt would be based on real-time monitoring of water temperature:

- Commence 2-Gates Project operations and OMR restrictions for larvae/juvenile delta smelt when the 3-station daily mean water temperatures at Mossdale, Antioch and Rio Vista ≥ 12ºC signaling a transition from adult to larvae/juvenile delta smelt management actions.
- Continue 2-Gates Project operations and OMR restrictions, consistent with boundary conditions of OMR discretionary operations, until June 30 or until the daily average temperature reaches 25ºC for 3 consecutive days at Clifton Court Forebay.

During this period, the OMR flow requirements are -1,250 cfs to -5,000 cfs (RPA 2 from the USFWS 2008 OCAP BO). In some years, conditions may occur when very large San Joaquin inflow may overwhelm tidal flows in the Old and Middle river channels. This would mask the effects of the Project.

July through November

The gates would not be operated from July through November and would remain in a fully open position.

References

Arthur. J.F., M.D. Ball, and S.Y. Baughman. 1996. Summary of federal and state water project environmental impacts in the San Francisco Bay-Delta Estuary, California. Pages 445-495 in J.T. Hollibaugh, editor, San Francisco Bay: the ecosystem. Pacific Division, American Association for the Advancement of Science, San Francisco, California.

Baxter, R., R. Breuer, L. Brown, M. Chotkowski, F. Feyrer, M. Gingras, B. Herbold, A. Mueller-Solger, M. Nobriga, T. Sommer and K. Souza. 2008. Pelagic Organism Decline Progress Report: 2007 Synthesis of Results. January 15, 2008. 52 pp.

Bennett, W. A. 2005. Critical assessment of the delta smelt population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science. 3(2): Article 1. http://repositories.cdlib.org/jmie/sfews

Bennett, W.A. 2009. Presentation at Interagency Ecological Program Modeling Workshop. May 27, 2009.

Brown, R., S. Greene, P. Coulston and S. Barrow. 1996. An evaluation of the effectiveness of fish salvage operations at the intake to the California aqueduct, 1979-1993. Pages 497-518 in J. T. Hollibaugh, ed. San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science, San Francisco, CA.

Brown, K. 2007. Evidence of spawning by green sturgeon, *Acipenser medirostris*, in the upper Sacramento River, California. Environmental Biology of Fishes. 79:297-303.

Brown, L.R. and D. Michniuk. 2007. Littoral fish assemblages of the alien-dominated Sacramento-San Joaquin Delta, California, 1980–1983 and 2001–2003. Estuaries and Coasts. Vol. 30(1): 186-200.

Brown, R. L. and W, Kimmerer 2002. Delta smelt and CALFED’s Environmental Water Account: a summary of the 2002 Delta Smelt Workshop. Prepared for the CALFED Science Program, October 2002.

California Department of Fish and Game (DFG). 2002. California Department of Fish and Game Comments to NMFS Regarding Green Sturgeon Listing. 129 p.

Chernick, M.R. (1999). Bootstrap Methods: a Practitioner’s Guide. Wiley and Sons, New York.

Dege, M. and L. R. Brown. 2004. Effect of outflow on spring and summertime distribution and abundance of larval and juvenile fishes in the upper San Francisco Estuary. Pages 49-66 in Feyrer, F., L. R. Brown, R. L. Brown, and J. J. Orsi (eds.). Early life history of fishes in the San Francisco Estuary and watershed. American Fisheries Society Symposium 39.

Feyrer, F., M. Nobriga, and T. Sommer. 2007. Multi-decadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences 64:723-734.

Fish, M., K. Hieb, D. Contreras, V. Afentoulis, J Messineo. 2008. 2007 Fishes Annual Status and Trends Report for the San Francisco Estuary. Interagency Ecological Program Newsletter 22(2):29-49.

Green, R.H. 1979. Sampling Design and Statistical Methods for Environmental Biologists. Wiley, New York.

Grimaldo L.F., R.E. Miller, C.P Peregrin, Z.P. Hymanson. 2004. Spatial and temporal distribution of native and alien ichthyoplankton in three habitat types of the Sacramento-San Joaquin Delta. American Fisheries Society Symposium 39:81-96.

Honey, K, R. Baxter, Z. Hymanson, T. Sommer, M. Gingras, and P. Cadrett. 2004. IEP Long-Term Fish Monitoring Program Element Review. Interagency Ecological Program for the San Francisco Bay / Delta Estuary.

Jassby, A. D., J. E. Cloern, and B. E. Cole. 2002. Annual primary production: patterns and mechanisms of change in a nutrient-rich tidal ecosystem. Limnology and Oceanography 47: 698-712.

Jassby, A.D. 2008. Phytoplankton in the Upper San Francisco Estuary: Recent Biomass Trends, Their Causes and Their Trophic Significance. San Francisco Estuary and Watershed Science. Vol. 6, Issue 1 (February), Article 2.

Kelley, J.T., A.P. Klimley, and C.E. Crocker. 2007. Movements of green sturgeon, *Acipenser medirostris*, in the San Francisco Bay Estuary, CA. Environmental Biology of Fishes 79:281-295

Kimmerer, W.J. 2008. Losses of Sacramento River Chinook salmon and delta smelt to entrainment in water diversions in the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science [online serial] 6 (2): Article 2. http://repositories.cdlib.org/jmie/sfews

Manly, B.J.F., and M.A. Chotkowski. 2006. Two new methods for regime change analysis. Archiv für Hydrobiologie 167: 593-607.

Monsen, N.E., J.E. Cloern, and J.R. Burau. 2007. Effects of flow diversions on water and habitat quality; examples from California's highly manipulated Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science 5, Issue 3 (July 2007), Article 2.

Moyle, P. 2002. Inland Fishes of California, 2nd Ed. University of California Press. Berkeley, CA.

Moyle, P.B., B. Herbold, D.E. Stevens and L.W. Miller. 1992a. Life history and status of delta smelt in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society 77:67-77.

Mueller-Solger, A.B., Hall, C. J., Jassby, A.D., and C.R. Goldman. 2006. Food resources for zooplankton in the Sacramento-San Joaquin Delta. Final Report to the CALFED Ecosystem Restoration Program, May 2006.

Nakamoto, R. J., T.T. Kisanuki, and G.H. Goldsmith. 1995. Age and growth of Klamath River green sturgeon (*Acipenser medirostris*). U.S. Fish and Wildlife Service. Project # 93-FP-13. 20 pages.

National Marine Fisheries Service (NMFS). 2009. Biological Opinion on the long-term Central Valley Project and State Water Project Operations Criteria and Plan. National Marine Fisheries Service, Southwest Region, Long Beach, CA. June 4, 2009. 844 pp.

National Marine Fisheries Service (NMFS). 2008a. Draft Biological Opinion on the long-term Central Valley Project and State Water Project Operations Criteria and Plan. National Marine Fisheries Service, Southwest Region, Long Beach, CA. December 11, 2008. 436 pp.

National Marine Fisheries Service (NMFS). 2008b. Proposed designation of critical habitat for the Southern Distinct Population Segment of North American Green Sturgeon: Draft Biological Report. National Marine Fisheries Service, Southwest Region, Long Beach, CA. September 2008. 90 pp.

Nobriga, M.L., T. Sommer, F. Feyrer, and K. Fleming. 2008. Long-term trends in summertime habitat suitability for delta smelt, *Hypomesus transpacificus*. San Francisco Estuary and Watershed Science. Vol. 6, Issue 1 (February), Article 1 http://repositories.cdlib.org/cgi/viewcontent.cgi?article=1109&context=jmie/sfews

Smith, P. 2009. Data Analyses and Modeling to Understand the Effects of Hydrodynamics on Delta Smelt Distributions and Abundance. Presentation at 2009 IEP Workshop 1: Physical Modeling and Fish Management. May 27, 2009.

Sommer, T, Armor, C, Baxter, R, Breuer, R, Brown, L, Chotkowski, M, Culberson, S, Feyrer, F, Gingras, M, Herbold, B, Kimmerer, W, Mueller-Solger, A, Nobriga, M, Souza, K. 2007. The collapse of pelagic fishes in the upper San Francisco Estuary. Fisheries 32(6):270-277.

Stevens, D.E. and L.W. Miller. 1983. Effects of river flow on abundance of young Chinook salmon, American shad, longfin smelt, and delta smelt in the Sacramento-San Joaquin river system. North American Journal of Fisheries Management 3:425- 437.

Stewart-Oaten, A. and Bence, J. R. 2001. Temporal and spatial variation in environmental impact assessment. Ecological Monographs 71: 305-39.

U.S. Fish and Wildlife Service (USFWS) 1995b. Sacramento-San Joaquin Delta Native Fishes Recovery Plan. U.S. Fish and Wildlife Service, Portland, Oregon.

U.S. Fish and Wildlife Service (USFWS). 2008. Biological Opinion on the Coordinated Operations of the Central Valley Project (CVP) and State Water Project (SWP). Final. December 15, 2008.

Appendices

Provided separately.