APPENDIX F

RMA Delta Smelt Particle Tracking and Behavior Analyses

Progression of Hydrodynamic Model Deployment and Development

Model Deployment

Early in the analyses process, it was determined that complex delta smelt behavioral models would be required to, with reasonable accuracy, predict distribution, abundance and fate of delta smelt under OCAP and 2-Gates operational conditions. Because the development of such a model would be time-consuming and its success could not be accurately predicted, a decision was made to initially use the One-Dimensional (1D) DSM2 model formulation for hydrodynamic, water quality and particle tracking to determine the most favorable location of gates, their region of control and their benefits under OCAP-modified flow conditions. While this effort was taking place, the RMA team was directed to develop reasonably accurate behavioral model using a Two-Dimensional (2D) RMA formulation, as modified to characterize both the adult and larvae/juvenile dealt smelt behavior. When developed, the 2D behavioral models would be used to determine effects of the 2-Gates Project for environmental documentation purposes under OCAP-adjusted hydrodynamic conditions.

One-Dimensional DSM2 Analyses

<u>Screening of Gate Alternatives, Determination of Region of Control, and Formation of Physical and Hydraulic Barrier Against Delta Smelt Migration.</u>

The above studies used the most recent historic DSM2 simulation available from the Department of Water Resources (DWR) for analyses of 2-Gates and flow control measures. DSM2 analysis (1) evaluated hydrodynamics, fate and transport of neutrally buoyant particles for OCAP BO and 2-Gates scenarios in comparison with the historic conditions, and (2) provided technical analyses of alternatives that provide equal or better protection of delta smelt at reduced water cost compared to OCAP conditions. DSM2 simulates riverine systems, calculates stages, flows, velocities and particle transport; and simulates many mass transport processes, including salts, temperature and THM formation.

<u>One-Dimensional DSM2 Model Numerical Basis.</u>

The partial differential equations of mass and momentum in the DSM2 hydrodynamic model component (HYDRO) are based on an implicit finite difference scheme. As a one-dimensional formulation, the channel length is divided into discrete reaches and the partial differential equations are transformed into finite difference forms for the discrete reaches by integrating numerically in time and space. The resulting equations are then linearized over a single iteration in terms of incremental changes in unknown variables (flow rate and water level) using approximations from truncated series, representing a function as an infinite sum of terms calculated from the values of its derivatives at a single point. When the discretized equations are written for all computational cells at the current time and the next time lines, it forms a system of equations which are solved simultaneously using an implicit algorithm.

The DSM2 water quality numerical solution (QUAL) is based on a model in which advection-dispersion equation is solved numerically using a coordinate system where computational nodes move with the flow. Because of the stability and accuracy of this approach it was used for a network of channels with many branches and junctions. The current version of QUAL simulates about 11 constituents moving in as many as 30 branches connected at junctions. The HYDRO flow model provides the needed information to move the computational nodes with mean channel velocity in the moving coordinate system thus accounting indirectly for advection part of the transport process. The dispersion part, however, is computed directly based on input dispersion coefficient and change in concentration gradient (2nd partial derivative) computed during simulation.

The DSM2 particle tracking component (PTM) computes the location of an individual particle at any time step within a channel based on velocity, flow and water level information provided by HYDRO. The longitudinal movement is based on transverse and vertical velocity profiles computed from mean channel velocity provided by HYDRO. Mean channel velocity is multiplied by a factor which depends on particle's transverse location in the channel resulting in a transverse velocity profile resulting in slower moving particles closer to the shore. Mean channel velocity is also converted to vertical velocity profile using a logarithmic profile to account for slower particles closer to the channel bottom. The longitudinal movement is then the sum of transverse and vertical velocities multiplied by time step. Particles also move across the channel and in vertical direction along the depth due to mixing. A random factor and mixing coefficients and the length of time step is used to compute the movement of particle in transverse and vertical direction.

Initial Site Screening Study using DSM2 Analyses.

DSM2 PTM analyses of 34 individual and combined gate alternatives in the central and south Delta were the basis of determining the optimum locations and number of gates. Two-gates on the Old River near Bacon Island and on Connection Slough provided optimum protection to delta smelt, while reducing water export cuts under OCAP operations. DSM2 analyses determined that other individual or combined gate alternatives provided less favorable water supply and fish protective benefits, channel capacity and geotechnical conditions, including: (1) two-gates on Old River at Quimby Island; (2) three-gates at Connection Slough, Railroad Cut, and Old River below Woodward; (3) four-gates on Connection Slough, Woodward and Railroad Cuts, and Old River below Woodward; (4) selective weir removal on Paradise Cut; (5) a weir on the San Joaquin River downstream of the head of Old River; and (6) Clifton Court Forebay gate tidal re-operations.

Region of Control Studies using DSM2 Analyses.

More than 140 PTM analyses using the DSM2 model, determined the 2-Gate Project to be very effective in controlling particle entrainment at the south Delta export facilities for a region largely bounded by the Old River, False River, Dutch Slough and Fisherman's Cut. Circulation patterns developed by one of the principle operations of the 2-Gate facilities (open on flood-tide and closed on ebb-tide) also promotes seaward movement of particles in Old River and away from the pumps. Further, operation of the 2-Gates is expected to improve water quality conditions in the south Delta.

2-Gate and Qwest Studies to form Physical/Hydraulic Control using DSM2 Analyses.
More than 320 PTM analyses determined that the 2-Gates Project operates compatibly with flow management measures on the San Joaquin River generated through OMR restriction during critical periods. These operations maintained the general distribution of adult delta smelt north and west of the region of control of the gates, forming a physical/hydraulic barrier to upstream smelt migration. Operations of the 2-Gate Project are shown to be consistent with the protective actions proposed by the U.S. Fish and Wildlife Service's OCAP Biological Opinion.

Two-Dimensional RMA-2 Analyses

Real-Time Operations under OCAP using Adult and Larvae/Juvenile Smelt Behavioral Models.

Adult Delta Smelt. To date, all of the modeling for near-term solutions have modeled adult delta smelt as neutrally-buoyant particles. While reasonably accurate for the larval stage, researchers have observed behaviors associated with turbidity and light in the adult stage. Analyses have also shown patterns of salinity and turbidity habitat may correlate with smelt abundance. Scientists have postulated that the adult smelt may be "surfing" the tides as a means of staying within their desirable habitat range. Modeling has been developed to impart habitat seeking behavior on the particles in the RMA-2 model. Once the smelt behavior model reasonably reproduced salvage patterns at the export facilities, additional simulations were done with barriers in the Old River and Connection Slough.

Larvae/Juvenile Delta Smelt. To correlate observed and modeled distributions and abundance of larvae/juvenile delta smelt, the RMA-2 and RMA-PTRK models have evaluated the full larval and juvenile delta smelt period, roughly from March through June, for differing hydrologic years. For each period, hatching rates have been determined by "tuning" to match 20mm survey observations and, if possible, observed salvage. The hatching period and mortality rates used in the simulations have been specified based on published findings from credible researchers. Delta smelt density predictions were compared with 20mm survey observations and the predicted delta smelt salvage was compared with salvage observations at the Skinner Fish Facility and the Tracy Fish Facility. Entrainment at exports, exited (flushed from) Delta, and within Delta were estimated, to determine the fate of fish by region of the Delta.

Two-Dimensional RMA Model Numerical Basis.

Resource Management Associates (RMA) has developed and refined models of the Sacramento-San Joaquin Delta system (Delta model) utilizing the RMA finite element models for surface waters (see Appendix D). 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) 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.

<u>2-Gate and OCAP Studies for OCAP BO Baseline and 2-Gates Conditions for Adult Delta Smelt using RMA Behavioral Analyses.</u>

Particle simulations with habitat seeking behavior were performed for historic periods. Particles were initially seeded in regions of acceptable habitat at the start of the simulations. Adult delta smelt habitat has been characterized by salinity (EC) and turbidity. Options were added to the model to influence sensitivity to habitat gradients, chance of incorrect directional choices, and resistance to tidal flow velocity. Behavioral characteristics were adjusted to attempt to replicate take at water export facilities. Two-Gates Project operations were compatible with flow management measures of the U.S. Fish and Wildlife Service's OCAP Biological Opinion. Delta smelt distribution, entrainment and fate have been determined using modified operations scenarios for the OCAP BO baseline and OCAP + the 2-Gate Project conditions using the RMA Adult Behavioral Model from December through February for the 2000, 2002, 2004 and 2008 historic periods.

<u>2-Gate and OCAP Studies for OCAP BO Baseline and 2-Gates Condition for Juvenile and Larvae Delta Smelt using RMA Behavioral Analyses.</u>

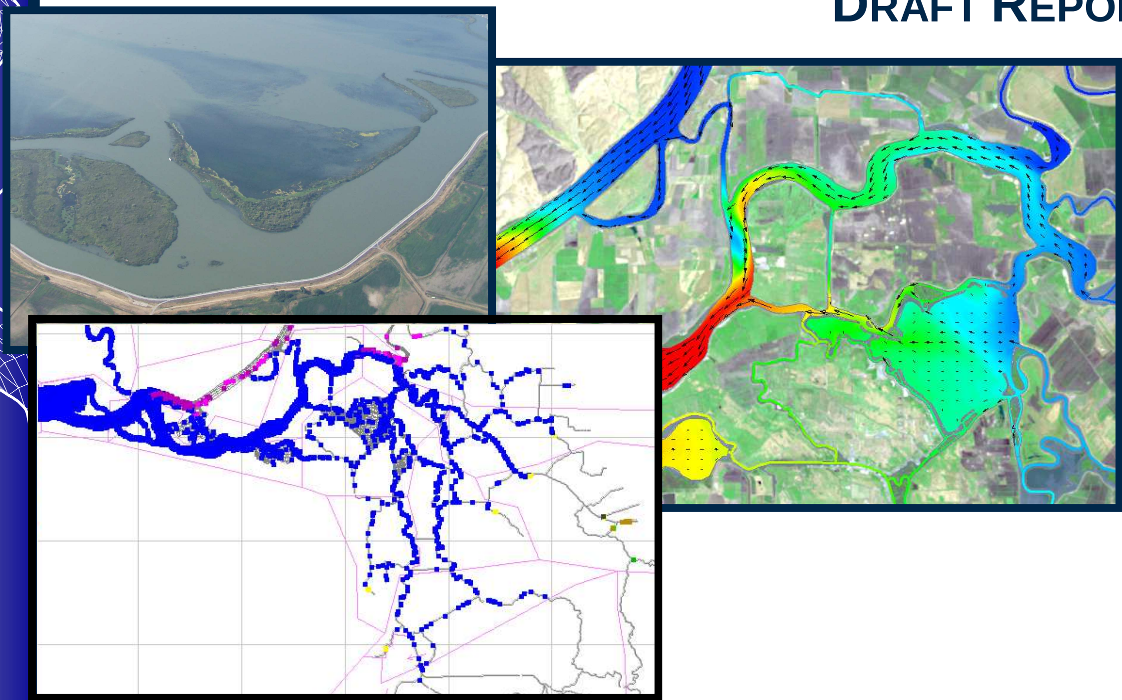
These simulations used the RMA Bay-Delta Model and RMA-PTRK for passive particle tracking with post processing analysis of hatching and mortality. The hatching rates estimated for historic conditions were applied without modification to the various operations scenarios. Therefore, the effect of the revised operations on delta smelt hatching rate and distribution were reflected in the simulation results. The simulations focused on the effect of the operations on delta smelt distribution and fate after initial hatching. Simulations were conducted roughly from March through June for the 2000, 2002, 2004 and 2008 historic periods. Modified operations scenarios were simulated for revised export flows according to OCAP guidelines and OCAP + the 2-Gates Project to determine delta smelt distribution, entrainment and fate.

Hydrodynamic Analysis of 2-Gates Near-Field Effects

Near-field hydrodynamic analyses have been conducted to assess the effects from the construction and operation of the 2-Gates Project on flood stage in Old River and Connection Slough, and on navigation vessels from velocities and potential scour patterns in the vicinity of the gates. A One-Dimensional hydraulic model was developed to assess changes in flood stage of the gates. The One-Dimensional model was then utilized as the basis for developing localized, Two-Dimensional models representing the immediate vicinity of each gate barrier. Normal- and low-flow simulations were conducted using the One-Dimensional model to generate boundary conditions for the Two-Dimensional models. The higher resolution Two-Dimensional numerical models were developed for the immediate vicinity of each of the gate barriers to assess velocity distributions through and near the gates. These current magnitudes and patterns were used to assess the potential for scour and develop recommendations for the rock aprons and other rip-rap, if needed. Current velocities and patterns were also used to assess any potential effects on navigation.

Particle Tracking and Analysis of Adult and Larval/Juvenile Delta Smelt for 2-Gate Fisheries Protection Plan

Draft Report



Prepared For:
Metropolitan Water District of Southern California

Contact:
Dennis Majors
dmajors@mwdh2o.com

Prepared By:
Resource Management Associates
4171 Suisun Valley Road, Suite J
Fairfield, CA 94534

Contact:
John DeGeorge
707-864-2950

April 29, 2009

Contents

Table of Figures

List of Tables

Introduction

This report describes the numerical modeling analysis of potential entrainment of adult, juvenile, and larval delta smelt in support of the 2-Gate Fisheries Protection Plan. The objective of the modeling analysis is to examine the incremental benefit of operable barriers in Old River and Connection Slough relative to proposed OCAP flow requirements in Old and Middle River.

Two distinct particle tracking techniques are used to represent the adult life stage and the larval/juvenile life stages. Adult delta smelt are not well represented using passive particle tracking techniques because they are sufficiently strong swimmers to resist tidal flows by moving out of the current and into shoals or near the bed where velocities are low. Entrainment 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. A particle behavior model has been developed by Resource Management Associates (RMA) with support from the Metropolitan Water District (MWD) to simulate the movement of adult delta smelt during this period 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 for MWD. In that study the DSM2-PTM 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 working 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 involve minimizing advective and dispersive transport from regions of the Delta where fish densities are highest.

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

This report is organized in three sections. The first section describes the RMA Bay-Delta Model and the set of hydrodynamic, EC, and Turbidity simulations prepared for this study. The second section describes the adult delta smelt modeling. And the final section describes the larval and juvenile delta smelt modeling.

RMA Model

Model Background

RMA has developed and refined a numerical model of the Sacramento-San Joaquin Delta system (Delta model) utilizing the RMA finite element models for surface waters. RMA2 (King, 1986) is a generalized free surface hydrodynamic model that is used to compute two-dimensional depth-averaged velocity and water surface elevation. RMA11 (King, 1995) is a generalized two-dimensional depth-averaged water quality model that computes a temporal and spatial description of conservative and non-conservative water quality parameters. RMA11 uses stage and velocity results from RMA2. As shown in Figure 1, the Delta model domain extends from Martinez to the confluence of the American and Sacramento Rivers and to Vernalis on the San Joaquin River.

The current version of RMA's Delta model has been developed and continually refined during numerous studies over the past 11 years. One of the most important additions has been the capability to accurately represent wetting and drying in shallow subtidal areas. The most comprehensive calibration efforts in recent years were performed during studies for CALFED (RMA, 2000), and Flooded Islands Feasibility Study (RMA, 2005).

The RMA model differs from DSM2 in that it uses a one- and two-dimensional representation, whereas DSM2 is solely a one-dimensional model. In addition, the RMA model tidal boundary can be set at Martinez or the Golden Gate, while DSM2 only uses the Martinez tidal boundary.

Model Capabilities

Hydrodynamic and water quality model output from RMA's Delta models, RMA2 and RMA11, provided temporal and spatial descriptions of velocities and water depths, and water quality, respectively, throughout the model domain. In the model, the results of the flow simulation are saved and used by the water quality model. The computational time step used for modeling the depth-averaged flow and water quality transport in the Delta is 7.5 minutes, and output from each model is saved every 15 minutes.

Due to the variable grid capability of the finite element method, fine detail can be added to emphasize specific areas in the vicinity of the current project without increasing detail elsewhere in the model grid. During the Suisun Marsh Levee Breach modeling project (RMA, 2000), considerable detail was added to the representation of Suisun Bay and the western Delta. Wetting and drying of the tidal mudflats was represented in sufficient detail to provide a good definition of change in the tidal prism with change in tidal stage.

Model Description

Finite Element Mesh

Figure 1 shows the entire finite element mesh (computational network) of the Delta model used for this study. A two-dimensional, depth-averaged representation was used for the Suisun Bay region, the Sacramento-San Joaquin confluence area, Sherman Lake, the Sacramento River up to Rio Vista, Big Break, the San Joaquin River up to its confluence with Middle River, False River, Frank's Tract and the surrounding channels, and the Delta Cross Channel. Suisun Marsh and Delta channels, and tributary streams were represented using a one-dimensional cross-sectionally averaged approximation.

The Delta finite element mesh was developed using an in-house GIS based graphical user interface program. This program allows for specification of the finite element mesh over layers of bathymetry points and contours, USGS digital line graph (DLG) and digital orthoquad (DOQ) images, and aerial photo surveys processed by USGS and Stanford University. Bottom elevations and the extent of mudflats were based on bathymetry data collected by NOAA, DWR, USACE and USGS. These data sets have been compiled by DWR and can be downloaded from DWR's Cross Section Development Program (CSDP) website at http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/csdp/index.html.

Additional data were collected around Franks Tract by DWR and the USGS in 2004. USGS 10 m resolution Delta Bathymetry grids were obtained from the Access USGS website at http://sfbay.wr.usgs.gov/access/Bathy/Delta/.

Boundary Conditions

Boundary conditions are specified for all inflow and export locations and for flow control structures. The locations of the model boundaries for the calibration grid are shown in Figure 1.

Tidal boundary

The tidal boundary is set at Martinez, the western boundary of the model, using observed data for the RSAC054 station at Martinez.

Flows, exports, precipitation, evaporation, Delta Islands Consumptive Use

Inflow locations in the model are shown in Figure 1.

Daily average flows 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. Data from Dayflow (http://www.iep.ca.gov/dayflow/index.html) and the IEP database (http://iep.water.ca.gov/dss/) are used to set these boundary conditions.

Delta Islands Consumptive Use (DICU) flows incorporate 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 (DWR, 1995).

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.

Hourly SWP export flows for 2003 and later years are computed using the Clifton Court gate ratings and inside and outside water levels. The flows are adjusted on a monthly basis so the total computed flow matches the monthly SWP export. For 2002 and earlier, when water levels inside and outside the gates were not available, SWP exports were defined using DSM2 flows into Clifton Court, modified to remove erroneously large flows. Further details on Clifton Court Forebay gate operations can be found in (RMA, 2000), RMA's Flooded Islands Feasibility Study (RMA, 2005), and in (DWR, 2005).

Electrical Conductivity (EC)

Electrical conductivity (EC) is used as a surrogate for salinity. The western EC boundary of the model, Martinez, is set using the average of top and bottom EC measurements at RSAC054. The Sacramento River EC boundary condition is set using daily Sacramento River at Hood data and the San Joaquin River EC boundary condition is set using daily San Joaquin River at Mossdale data. The Sacramento River EC time series is also applied to Yolo Bypass. EC boundary conditions for all other inflows are set to constant estimated values.

Turbidity

For the 1999-2004 simulations, sufficient turbidity data were not available to set model boundary conditions and therefore, during previous work (RMA, 2008), suspended sediment concentration (SSC) was simulated using USGS data. For the current study, it was necessary to simulate turbidity because USFWS OCAP BO triggers were based on turbidity. Therefore, SSC data had to be translated to turbidity.

Suspended sediment concentrations tend to be roughly half of turbidity concentrations (Dave Fullerton, personal communication). To test this theory, this conversion was applied during periods when both turbidity and SSC data were available. The factor of 0.5 produced reasonable matches for Sacramento River and San Joaquin River data. These matches were better than those resulting from applying relationships found in literature.

For the Martinez boundary, only USGS Mallard SSC data were available for the periods of interest. Comparisons between Mallard SSC (in mg/L) and turbidity (in NTU) at Benicia showed very similar values for the two data sets. A relationship from literature did not produce a good match at all. Thus no adjustment was applied to the Mallard SSC data for use as turbidity boundary condition at Martinez.

For the 2007-2008 period, turbidity data were available from CDEC at Martinez, Sacramento River at Hood and San Joaquin River at Vernalis.

For all years, the Sacramento River turbidity boundary condition was also applied to Sacramento River, Yolo Bypass, Cosumnes River and Mokelumne River. No turbidity value was applied to the miscellaneous eastside flows.

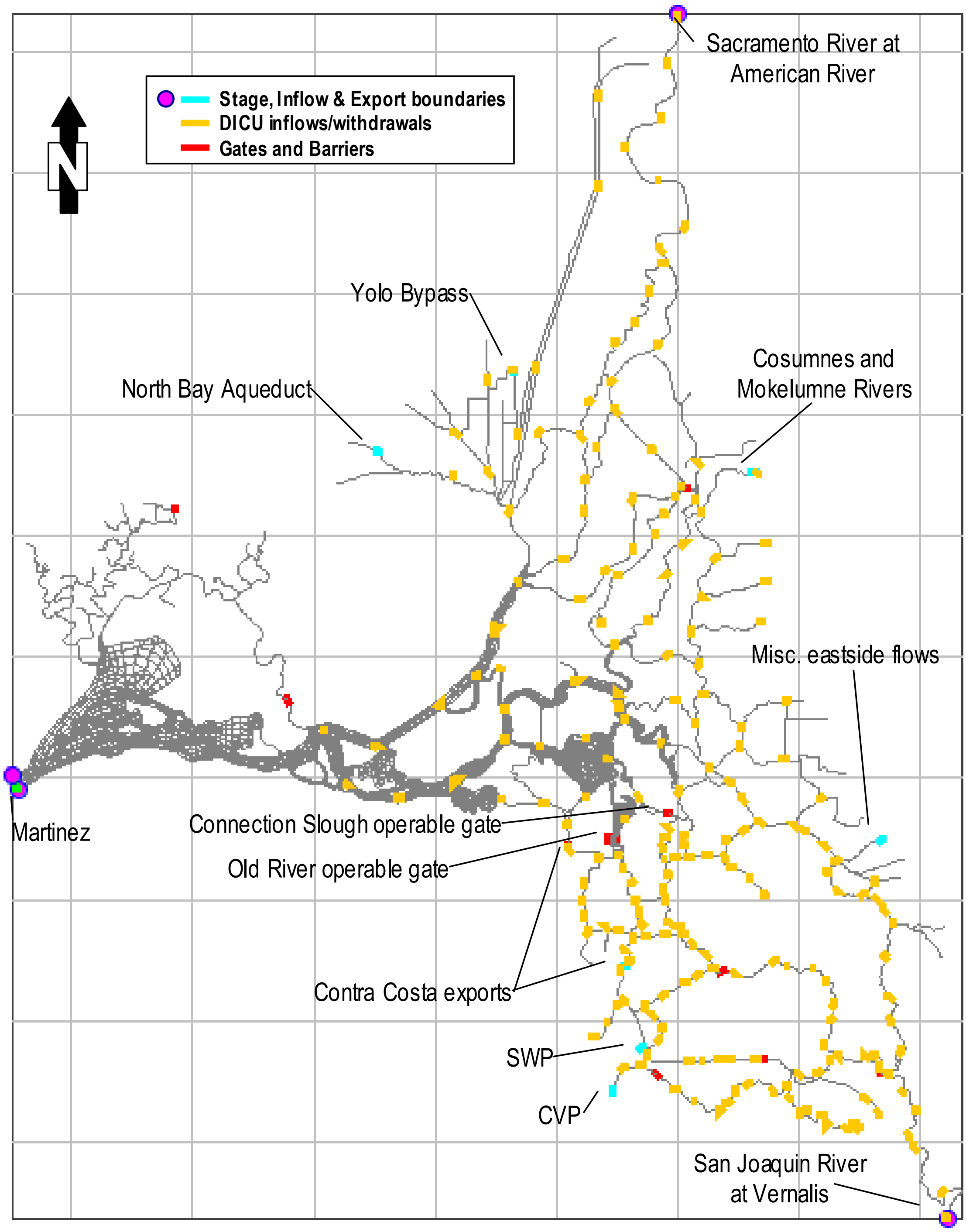


Figure 1 Model grid showing stage, inflow, export, DICU, gate and barrier locations.

Hydrodynamic, EC and Turbidity Simulations

Analysis periods

For each analysis period, hydrodynamic simulations were performed for November through June and water quality (EC and turbidity) simulations were performed for November through March. November was used as a spin-up period and was not used in the particle tracking simulations. Years simulated include:

- 1999-2000
- 2001-2002
- 2002-2003
- 2003-2004
- 2007-2008

Net Delta outflow (net flow leaving the Delta) for each December through June simulation period is plotted in Figure 2. The first four periods were selected based on distinct smelt salvage events. The 2007-2008 period was selected because of good availability of turbidity data for setting model boundary conditions. Of these years, the highest flows occurred in 2004, while 2007-2008 was a driest period.

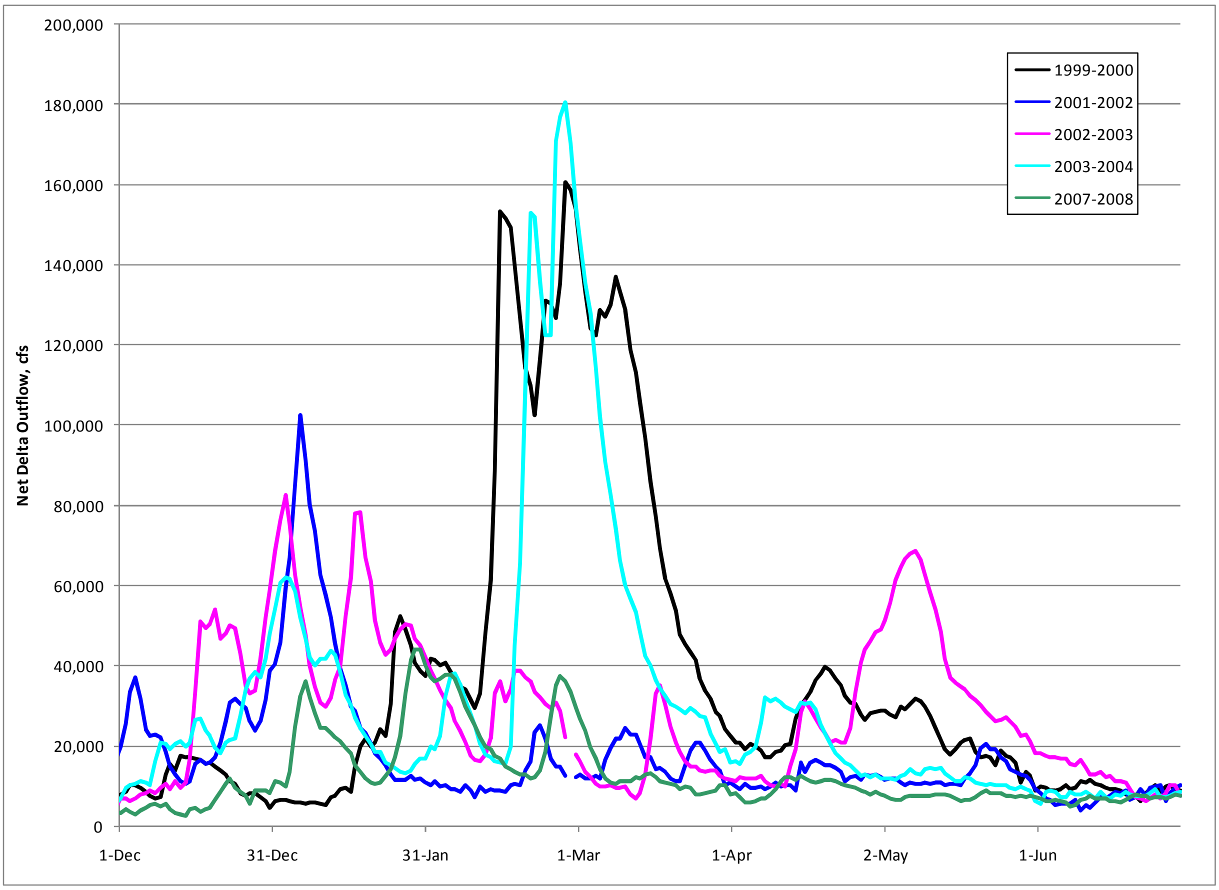


Figure 2 Net Delta Outflow for each December through June simulation period.

Simulations

For each analysis period, historical hydrodynamic and water quality simulations were performed. All stage, inflows, exports, and operations of existing gates and barriers reflected historical conditions.

The next set of simulations reflected OCAP requirements, defined as the Reasonable and Prudent Actions (RPAs). Exports were modified to achieve OCAP Biological Opinion (BO) Old + Middle River (OMR) flow limits. OMR flows are calculated by computing the sum of the net flows at ROLD024 and RMID015 (Middle River) and ROLD024 (Old River at Bacon Island). Station locations are shown in Figure 3.

There are two periods of flow limitations. The first period, under RPA 1, sets OMR flow limits at -2000 cfs and the second period, RPA 2, sets flow limits between -1250 cfs and -5000 cfs. To accommodate the range for RPA 2, "lower bound" and "upper bound" simulations were performed with OMR flows at

-1250 cfs and -5000 cfs, respectively. Turbidity limits determined the timing of onset of RPA 1. The presence of spent delta smelt in the Spring Kodiak Trawls or the Tracy Fish Collection Facility (TFCF) and Delta –wide temperature determines the onset of RPA 2 as discussed below. During VAMP (Vernalis Adaptive Management Program) from April 15 through May 15, all export reductions were suspended.

"With Project" simulations were performed using operable gates in Old River and Connection Slough. The with Project simulations adhered to the OCAP flow limits with earlier trigger dates for RPA 1.

"No project" simulations were also run using this earlier trigger date so that direct comparisons could be made to determine the effects of the gates alone.

Inflows were not modified for the OCAP or two-gate/OCAP simulations, and therefore net Delta outflow (NDO) increased, resulting in reduced EC at Martinez. The G-model was used to modify the Martinez EC boundary condition based on the increased NDO. The G-Model is a salinity-outflow relationship based on a set of empirical equations developed from the one-dimensional advection-dispersion equation (Denton, 1993).

The G-model (DWR, 2005) is used to compute Martinez EC using historical NDO then using the OCAP increased NDO. The resulting EC computed for historical NDO was not an exact match with the observed historical EC used for the model boundary condition. Therefore, the difference between the two G-model computed EC time series was used to adjust the historical Martinez EC used in the model.

Triggers

OCAP

The RPA 1 trigger, limiting OMR flows to -2000 cfs, was based on turbidity conditions in the Delta. When the three-day-average turbidity from the historical simulations at each of three stations (Prisoner's Pt, Holland Cut and Victoria Canal – locations shown in Figure 3) is ≥ 12 NTU, RPA 1 was triggered. If historical smelt salvage data showed an increase in salvage before this turbidity trigger is reached, RPA 1 began sooner based on a qualitative assessment of the salvage data.

RPA 2, adjusting the OMR limit to -1250/-5000 cfs, is triggered by observed temperature data and or confirmation that delta smelt have begun spawning. When daily mean water temperatures at Mossdale, Antioch and Rio Vista is ≥ 12° C, RPA 2 begins. RPA 2 can be suspended any time the three day average flow on Sacramento River at Rio Vista is ≥ 9,000 cfs and three day average flow on San Joaquin River at Vernalis is ≥ 10,000 cfs between the start of RPA 2 and June 30 or is suspended earlier when suspended earlier due to daily average water temperatures reaching 25° C for three consecutive days at Clifton Court Forebay.

CDEC and BDAT temperature data were used to check for the temperature triggers. USGS flow data were used to check for the flow triggers.

Two-Gates

For the with Project simulations, RPA 1 and gate operations begin when simulated historical turbidity at Jersey Point reaches 12 NTU. This turns out to be from 3 to 21 days earlier than the RPA 1 trigger for the OCAP simulations. The RPA 2 trigger is unchanged for the with Project simulations.

No project simulations were also run using this earlier trigger date so that direct comparisons could be made to determine the effects of the Project alone.

A summary of trigger dates is provided in Table 1, with the final operating schedule in Table 2.

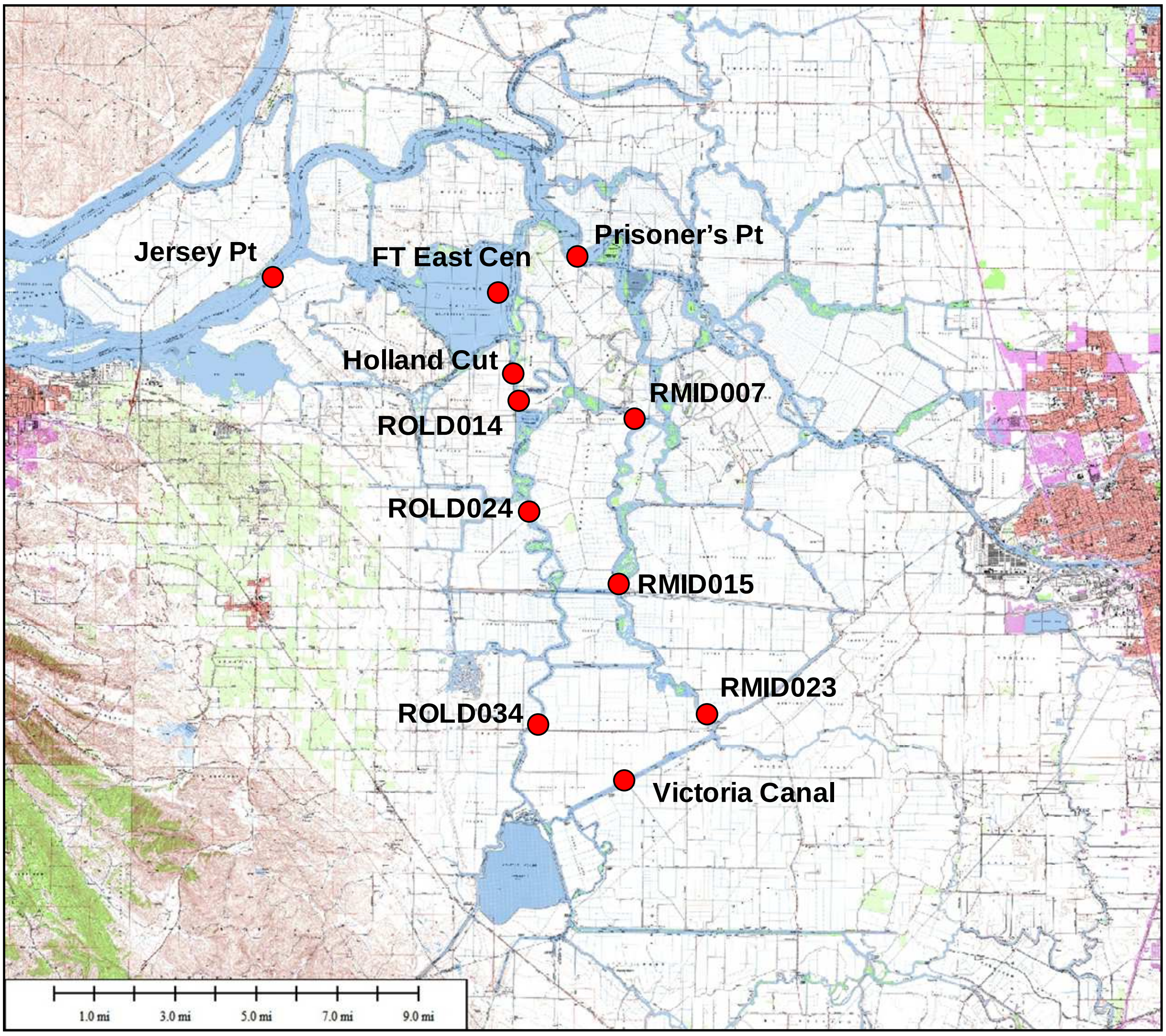


Figure 3 Station location map.

Table 1 Summary of turbidity, temperature and flow triggers for OCAP and two-gate operations

	Triggers					
Analysis Period	**3 station 3-day avg turbidity ≥ 12 NTU**	**Sooner based on salvage data?**	**Jersey Pt 3-day avg turbidity ≥ 12 NTU**	**3 station daily mean water temps ≥ 12 C**	**Suspend RPA 2 Rio Vista ≥9000 cfs, Vernalis ≥10,000cfs**	**Clifton Court ≥ 25° C for 3 days**
Dec 1999 - Jun 2000	7-Feb-00	1-Feb-00	28-Jan-00	13-Mar-00	19-Feb-00 to 23-Mar-00	--
Dec 2001 - Jun 2002	16-Dec-01	no	7-Dec-01	21-Feb-02	--	--
Dec 2002 - Jun 2003	30-Dec-02	23-Dec-02	20-Dec-02	25-Feb-03	--	4-Jun-03
Dec 2003 - Jun 2004	29-Dec-03	no	19-Dec-03	21-Feb-04	--	19-Jun-04
Dec 2007 - Jun 2008	7-Feb-08	1-Feb-08	11-Jan-08	2-Mar-08	--	--

Table 2 Final schedule for OCAP and two-gate operations

	Final Schedule			
Analysis Period	**RPA 1: OMR -2000 cfs**	**2gate/RPA 1:OMR -2000 cfs**	**RPA 2: OMR -1250/-5000 cfs***	**Return to historic flows**
Dec 1999 - Jun 2000	1-Feb-00	28-Jan-00	23-Mar-00	30-Jun-00
Dec 2001 - Jun 2002	16-Dec-01	7-Dec-01	21-Feb-02	30-Jun-02
Dec 2002 - Jun 2003	23-Dec-02	20-Dec-02	25-Feb-03	4-Jun-03
Dec 2003 - Jun 2004	29-Dec-03	19-Dec-03	21-Feb-04	19-Jun-04
Dec 2007 - Jun 2008	1-Feb-08	11-Jan-08	2-Mar-08	30-Jun-08

*RPA 2 is suspended during VAMP: 15-Apr to 15-May

Determination of Exports for OMR flow requirements

A regression method was used to determine export reductions required to achieve the OMR flow requirements. The regression method considered south Delta demand (SWP, CVP, Contra Costa and south Delta DICU), San Joaquin River flow, south Delta barrier operations and historical OMR flow. Two iterations of the regression computations generally produced 14-day average OMR flows within 5% of the desired goal.

During times when OMR flows were outside the OCAP requirement, no adjustment was made to exports (i.e. exports were not increased to raise OMR flows to the OCAP limit).

An example of simulated OMR flows in comparison with the OCAP flow goal is plotted in Figure 4. The blue line shows the OCAP RPA1 OMR negative flow restriction, which is 2000 cfs from 29-Dec-03 until 2-Mar-04. For this case, the RPA 2 OMR negative flow restriction is set at 1250 to 5000 cfs from 2-Mar-04 through 19-Jun-04. Note that the OCAP negative flow restrictions cease during VAMP from 15-Apr-04 until 15-May-04. Simulated historical 1-day average OMR flow is shown in red. Simulated historical flows with OCAP 1-day average and 14-day average OMR flow are shown in green and black, respectively.

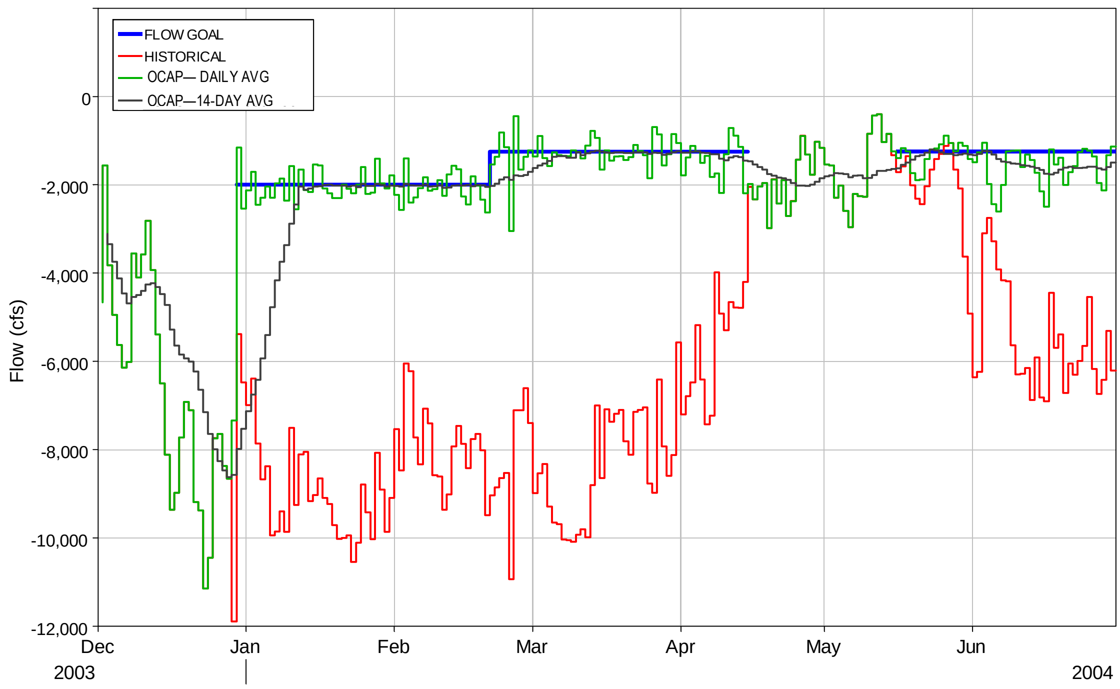


Figure 4 Simulated historical and OCAP (daily and 14-day average) Old + Middle River flows in comparison with OCAP flow goal for December 2003 - June 2004.

Results and Discussion

The primary drivers of the pre-spawning Adult smelt model (discussed in the following section) are hydrodynamics and turbidity. Smelt are thought to seek more turbid environments (USFWS, 2008). During high river flow periods, turbidity enters the Delta from the Sacramento River and Georgiana Sloughs and enters the south Delta through Old River and Middle River. When these two water bodies meet, they form a turbidity bridge that allows smelt to move to locations in close proximity to the influence of the SWP and CVP facilities, placing them at high risk for entrainment at the export pumps.

Water management actions (operation of the SWP and CVP export pumps) consistent with the OCAP RPA actions, by reducing negative Old and Middle River flows, prevents or delays the turbidity bridge from forming, thus keeping smelt away from the export pumps. The proposed operable gates in Old River and Connection Slough, when operated in conjunction with OMR flows can provide more flexibility in keeping turbidity away from the pumps.

Color contour plots of turbidity show the effectiveness of OCAP RPA actions and gate operations compared to OCAP actions alone. With minimum contours plotted at 12 NTU, these plots show whether or not a turbidity bridge forms. If turbidity exceeds 12 NTU all the way through Old and/or Middle River to the export facilities, smelt are more likely to pass through and become entrained.

Example turbidity contour plots are provided in Figure 5 and Figure 6 for the 2002-2003 and 2003-3004 simulation periods. These plots show turbidity for historical conditions, operation of the SWP and CVP export pumps consistent with the OCAP actions, Project facilities operated to balance Old and Middle River flows, and operation of the SWP and CVP export pumps consistent with the OCAP actions with the same start time as the Project simulations.

On 05 Jan 2003, the operation of the SWP and CVP export pumps consistent with the OCAP actions reduce turbidity in the south Delta below historical levels, however the turbidity bridge still forms. With the two gates in place and operating to balance flows, the turbidity bridge does not form. The operation of the SWP and CVP export pumps consistent with the OCAP actions with the earlier start date (in this case, the start date is 3 days earlier), the turbidity bridge does not form, however the gap is much smaller than with the Project.

On 27 December 2003, the turbidity bridge forms with operation of the SWP and CVP export pumps consistent with the OCAP actions, but not with the earlier start date. The earlier start date results are similar whether the gates are in place or not. In this case, there is a ten-day difference between the start dates.

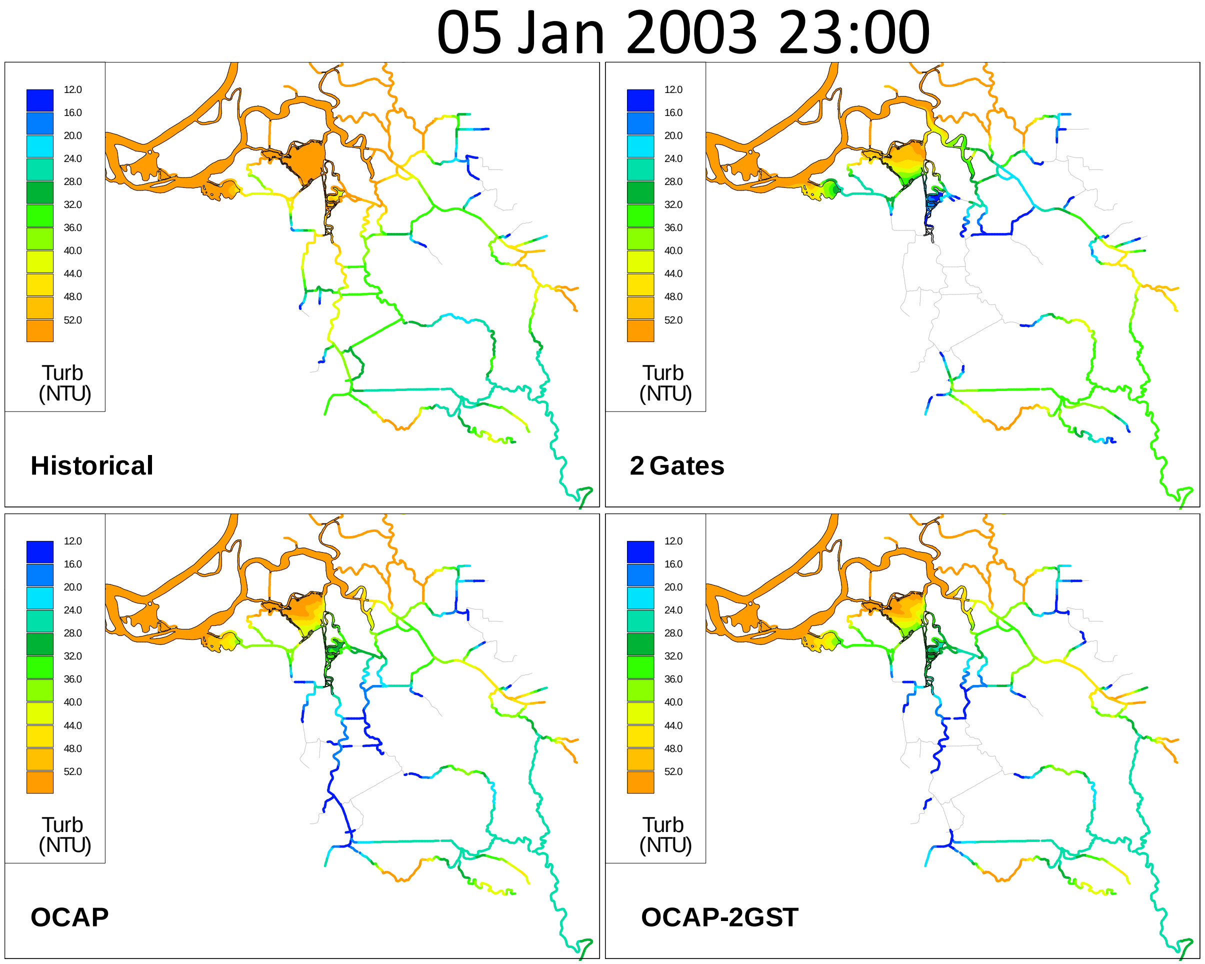


Figure 5 Simulated turbidity for historical conditions, OCAP operations, 2-gate scenario, and OCAP operations with 2-gate start time (OCAP-2GST) on 05 Jan 2003 at 23:00.

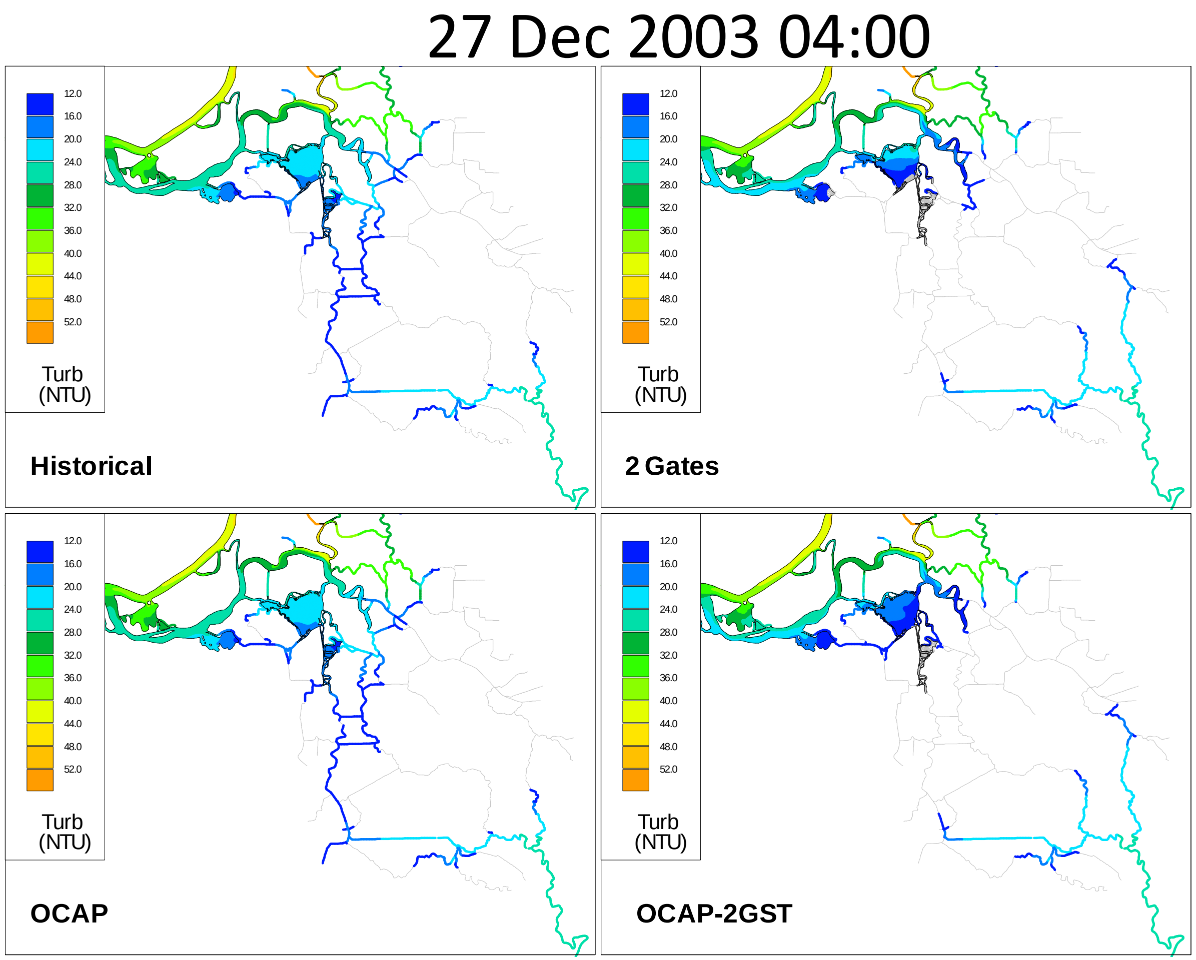


Figure 6 Simulated turbidity for historical conditions, OCAP operations, 2-gate scenario, and OCAP operations with 2-gate start time (OCAP-2GST) on 27 Dec 2003 at 04:00.

Gate Optimization

Several Project operations were examined. Under existing conditions, Old River is a faster path vs. Middle River for turbidity entering from the north Delta and then on to the export facilities in the south Delta. By closing the gates in Old River and Connection Slough during portions of the flood/ebb tidal cycle, Old River and Middle River net flow and tidal mixing can be modified to achieve the longest travel time for the turbidity laden waters to reach the export locations. With the overall increased travel time, turbidity decreases with settling, reducing the chance of a turbidity bridge forming and connecting the south and central Delta.

Figure 7 compares the net flows on Old and Middle Rivers for the no project condition and a 2-gate operation which “balances” the turbidity travel along the Old and Middle River channels. In the “balance” operation, the gate on Connection Slough is always closed, while the Old River gate is open and closed over some portion of the tidal cycle. When both gates are closed during a flood tide period, flow directly from Franks Tract to the south Delta is blocked. Water does reenter the Old River channel from Middle River along the east-west channels north and south of Woodward.

The adjustment in the Old River and Middle River net flows shown in Figure 7 can be accomplished by a range of gate closing/opening over the flood and ebb tidal cycles. Closing the Old River gate ½ to 1½ hours per day during the flood tide is sufficient time to accomplish the net flow changes displayed in Figure 8. Alternatively, the Old River gate may be closed for the entire flood tide period and the subsequent ebb tide period in order to achieve the same change in net flows. With this operation, the gate would be closed about 12 hours/day. This mode of operation would be more intrusive to boating and fish passage, but might further retard the southern movement of turbidity along Old River by decreasing the tidal mixing.

Figure 9 and Figure 10 compare the computed tidally averaged turbidity for the OCAP-2GST (OCAP with 2-gate start time) conditions for no gates, and the 2-gate configuration with the 12 hr/day closure time (of the Old River gate) and the ½ to 1½ hr/day closure during the flood tide only. Figure 9 shows for the January 20, 2004 date, the limited Old River gate closure operation is as effective as the 12 hr/day operation in maintaining the turbidity gap in the south Delta. Figure 10 shows the results for the March 20, 2004 date. For this date, the limited Old River gate closure operation does a good job of maintaining the turbidity gap in Old River, but is overall slightly less effective than the 12 hr/day closure operation.

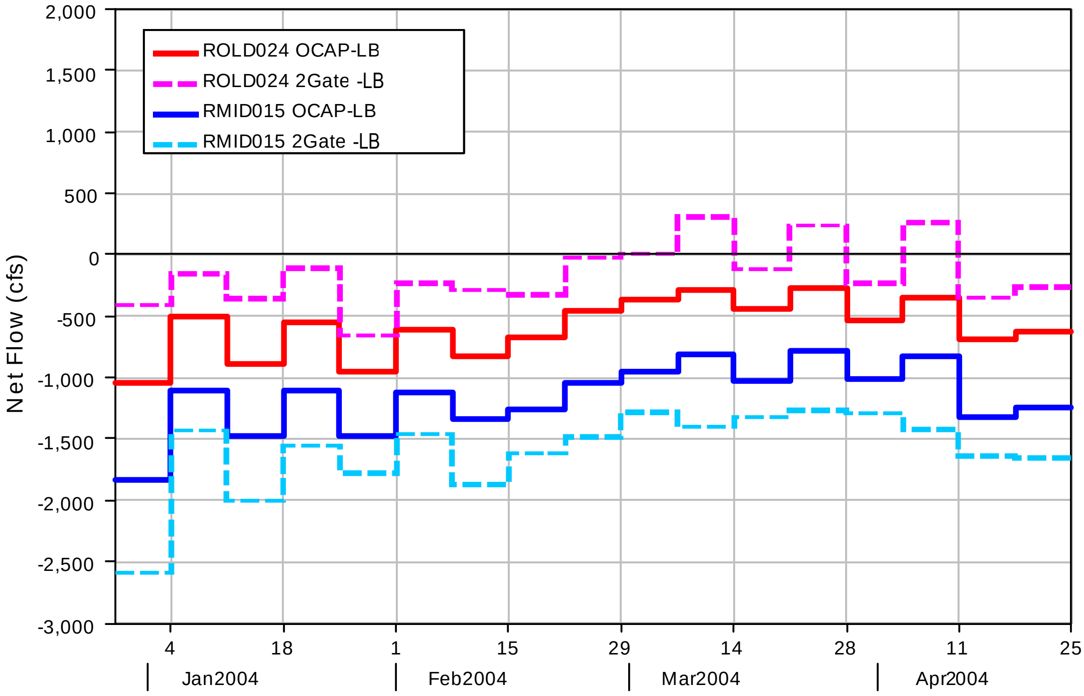


Figure 7 Net flow on Old and Middle Rivers at Bacon Island for no gates (OCAP-LB2) and the "balanced" gate operation (2Gate-OCAP-LB2).

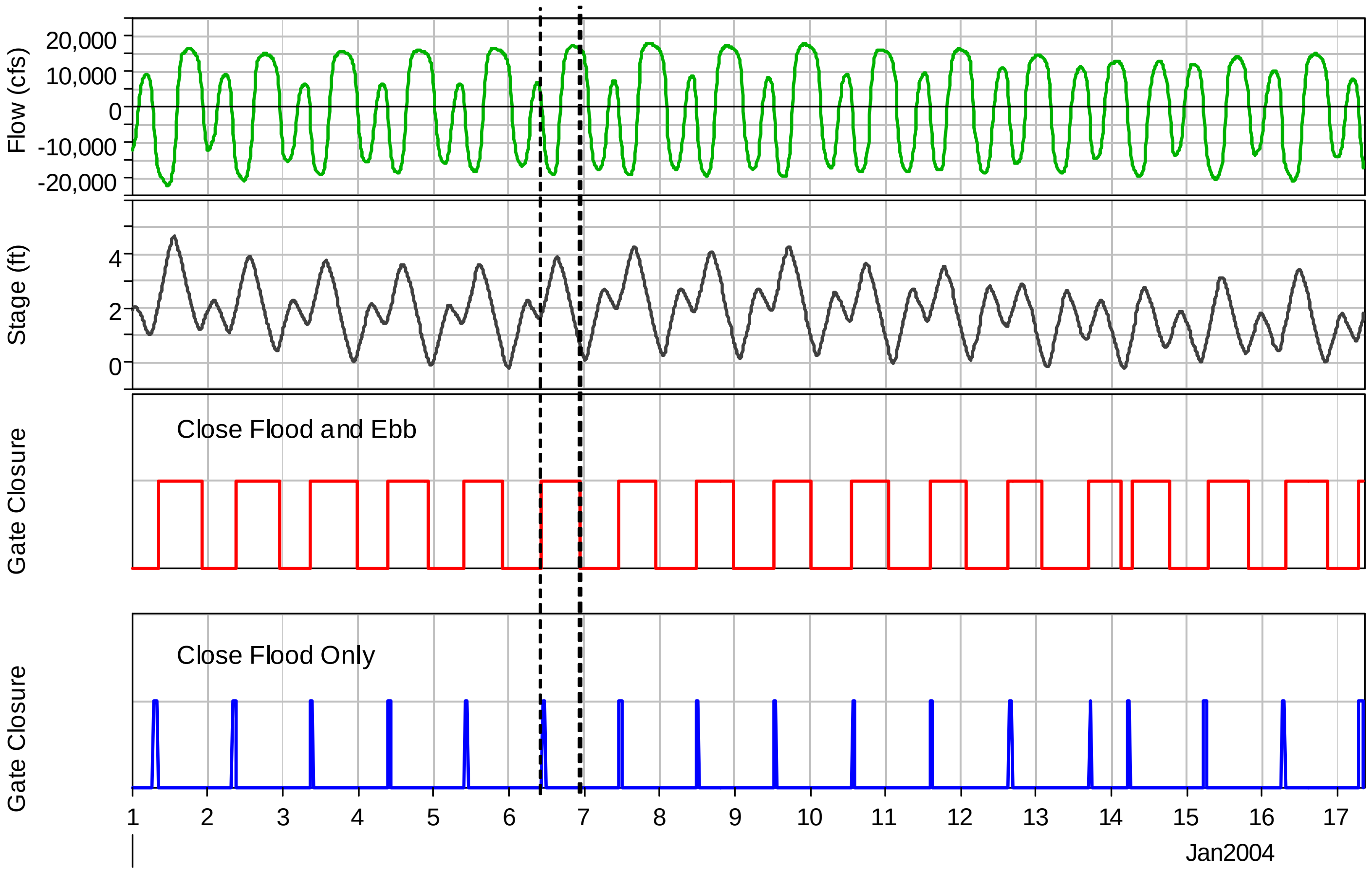


Figure 8 Old River gate operations employed to divert net flow from Old River. The "Close Flood and Ebb" and "Close Flood Only" operations reduce the Old River net flow approximately same degree.

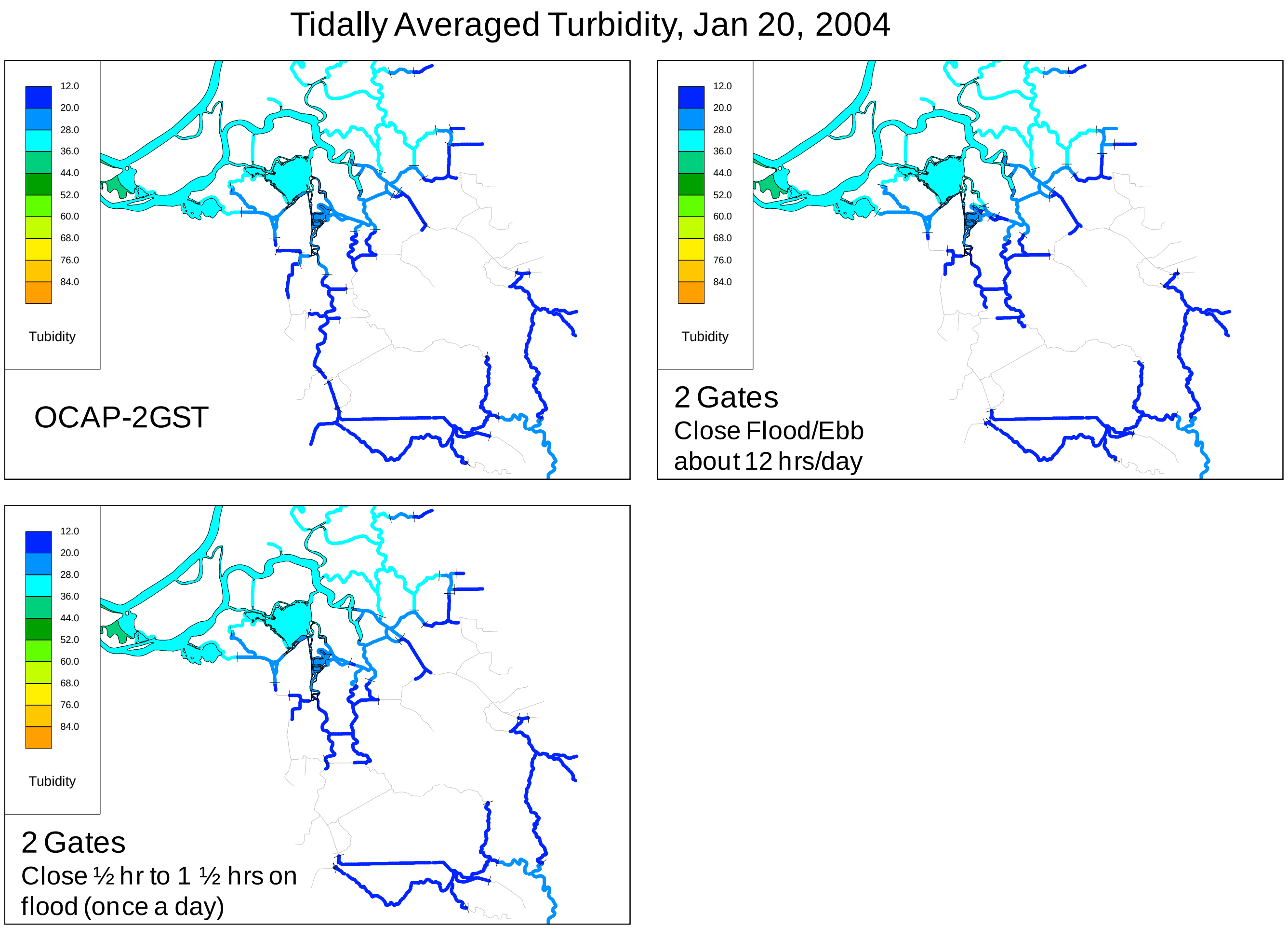


Figure 9 Comparison of simulated turbidity for OCAP operations with 2-gate start time (OCAP-2GST), and the 2-gate scenario with OCAP-2GST conditions. The 2-gate results compare Old River gate closure over the flood/ebb period (12 hrs/day) and for a more limited closure time (½ to 1½ hrs/day on flood tide only). Results are for January 20, 2004.

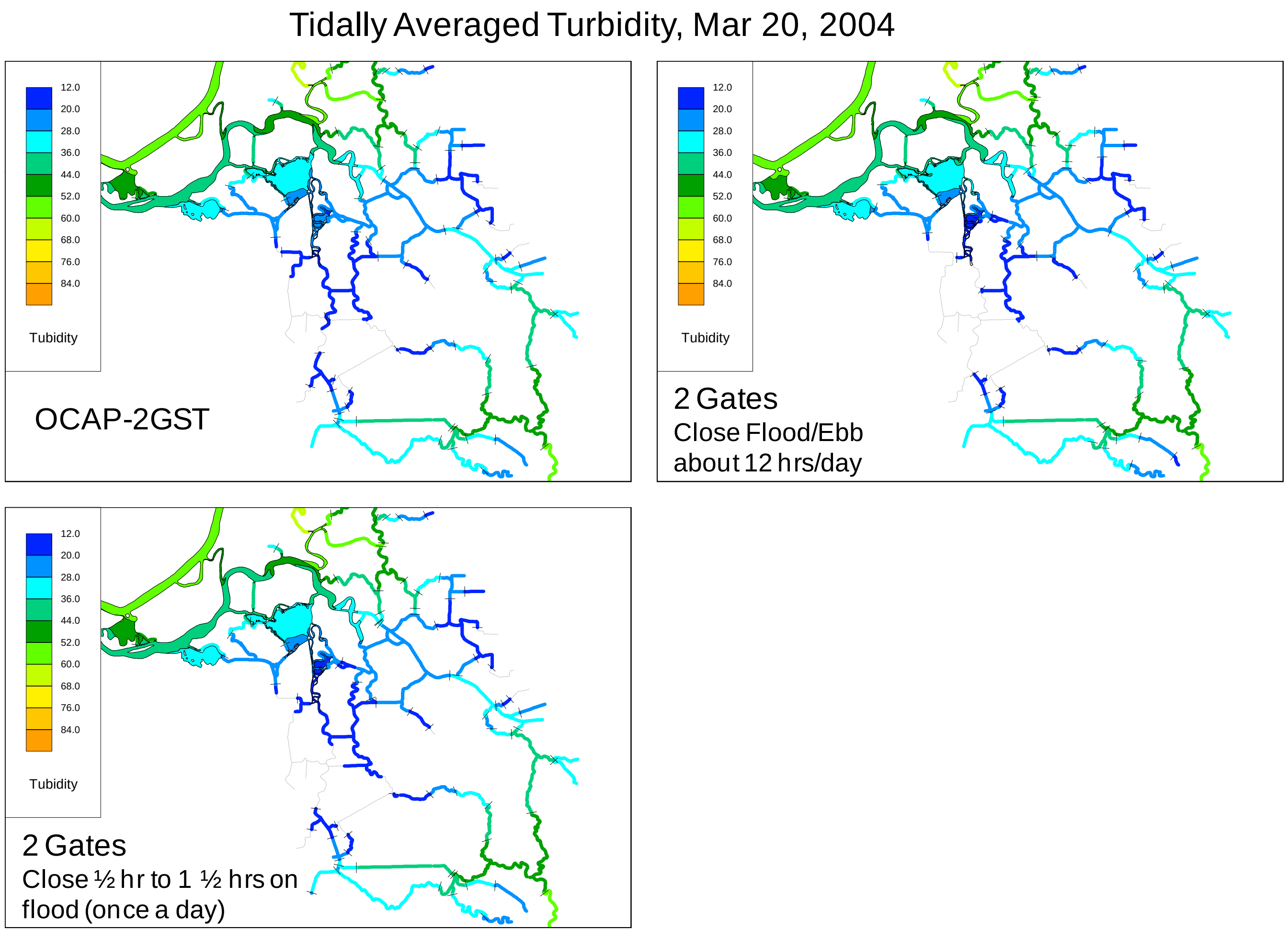


Figure 10 Comparison of simulated turbidity for OCAP operations with 2-gate start time (OCAP-2GST), and the 2-gate scenario with OCAP-2GST conditions. The 2-gate results compare Old River gate closure over the flood/ebb period (12 hrs/day) and for a more limited closure time (½ to 1½ hrs/day on flood tide only). Results are for March 20, 2004.

Two Gates with Increased OMR Flows

Once the optimal gate operations were determined, simulations were performed to test how much increase in negative OMR flows could be achieved without increasing smelt entrainment. OMR flows were increased to -3000 cfs, - 4000 cfs and -5000 cfs for the entire simulation period (except during VAMP).

OMR Flow Optimization

The period Nov 2003 – Jun 2004 was computed for a wide range of OMR flow conditions. The set of simulations provide a broad data set for evaluating the change in south Delta turbidity with changing OMR flow. If the presence of adult delta smelt can be correlated to turbidity, then an operational objective is to manage negative Old and Middle River flows and the 2-gate operation to reduce the movement of high turbidity water from the northern Delta down to the export facilities.

Figure 11 presents curves of turbidity time series for Dec 1, 2003 to Mar 31, 2004 for a 2-gate simulation with constant -3000 cfs OMR flow from Dec 19, 2003 to Mar 31, 2004. Time series are plotted at the Old River stations ROLD014, ROLD024 and ROLD034 and for a location near the eastern edge of Franks Tract (station locations are shown in Figure 3). Figure 11 shows that the turbidity peaks apparent in the Franks Tract curve over time migrate south on Old River towards the Delta export locations. Model analysis shows this movement of turbidity southward occurs from tidal mixing and the negative OMR flows. A similar process occurs on Middle River where high turbidity waters from the northern Delta move south to the export locations. The goal of the “OMR flow optimization” simulations was to maintain turbidity at ROLD034 at or below 15 NTU to preserve the “turbidity gap”, while also increasing export flows when feasible.

OMR restrictions in the 2003-2004 simulations begin Dec 19, 2003. Figure 11 shows that at times turbidity exceeds 15 NTU at ROLD034, while during other periods turbidity is well under 10 NTU. Results from a second more “optimized” simulation are presented in Figure 12. Export flows were modified to decrease negative OMR flow when Franks Tract turbidity was high and increase exports to take advantage of available water when Franks Tract turbidity was low. Turbidity at ROLD034 for the “optimized” simulation is consistent over time and never exceeds 15 NTU. The cumulative negative OMR flow for the optimized condition is approximately that of the constant -3000 cfs OMR flow case. The ROLD034 turbidity for the “optimized” run presented indicates a potential for some further increase in export flow while maintaining turbidity levels below 15 NTU.

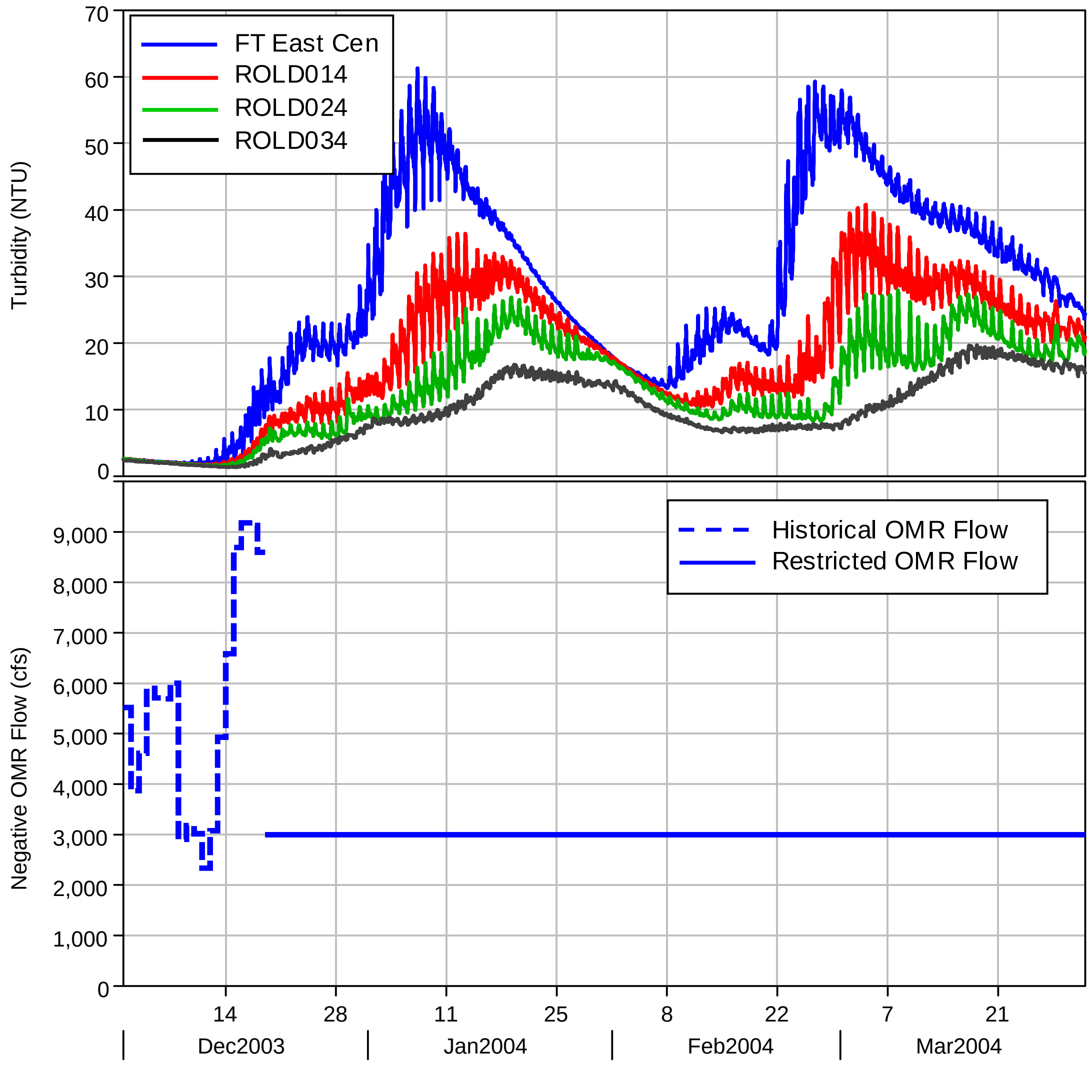


Figure 11 Simulation turbidity time series (top) for 2003-2004 2-gate scenario, with OMR flows at -3000 cfs from Dec 19, 2003 to Mar 31, 2004 (flows shown in bottom plot).

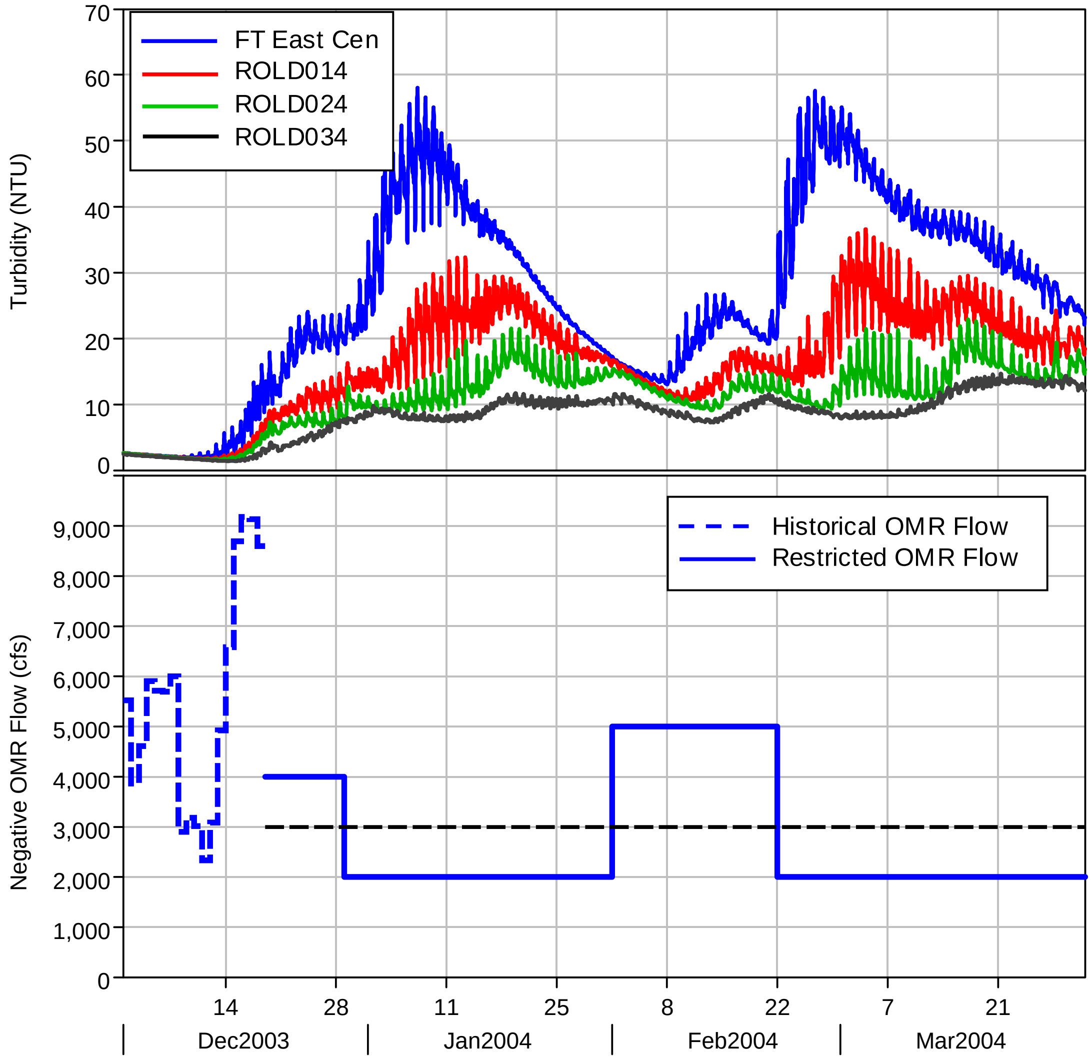


Figure 12 Simulation turbidity time series (top) for 2003-2004 2-gate scenario, with OMR flow restrictions beginning Dec 19, 2003. OMR flows were decreased when Franks Tract turbidity was high and increased when Franks Tract turbidity was low (flows shown in bottom plot).

Salinity Impacts

Reduced exports during wet weather periods tend to increase salinity in the south Delta relative to historical conditions because the fresher (and more turbid) water is not being pulled south. Gate operations result in a small additional increase in salinity south of the gates. Example plots of tidally averaged EC (a surrogate for salinity) are shown in Figure 13 through Figure 16 for the 2003-2004 simulation period. Station locations are shown in Figure 3.

At ROLD014 (Figure 13), downstream of the Old River gate, and RMID007 (Figure 14), just east of the Connection Slough gate, the OCAP-LB and 2GATE-LB tidally averaged EC are 50 to 250 umhos/cm higher than historical. At these locations, the EC changes are primarily due to export reductions as the 2GATE results are very similar to the OCAP results.

At ROLD024 (Figure 15), upstream of the Old River gate, the OCAP tidally averaged EC result is as much as 270 umhos/cm higher than historical, and the 2GATE results is as much as 360 umhos/cm higher than historical. Further upstream at ROLD034 (Figure 16), the OCAP tidally averaged EC result is as much as 350 umhos/cm higher than historical, and the 2GATE results is as much as 390 umhos/cm higher than historical

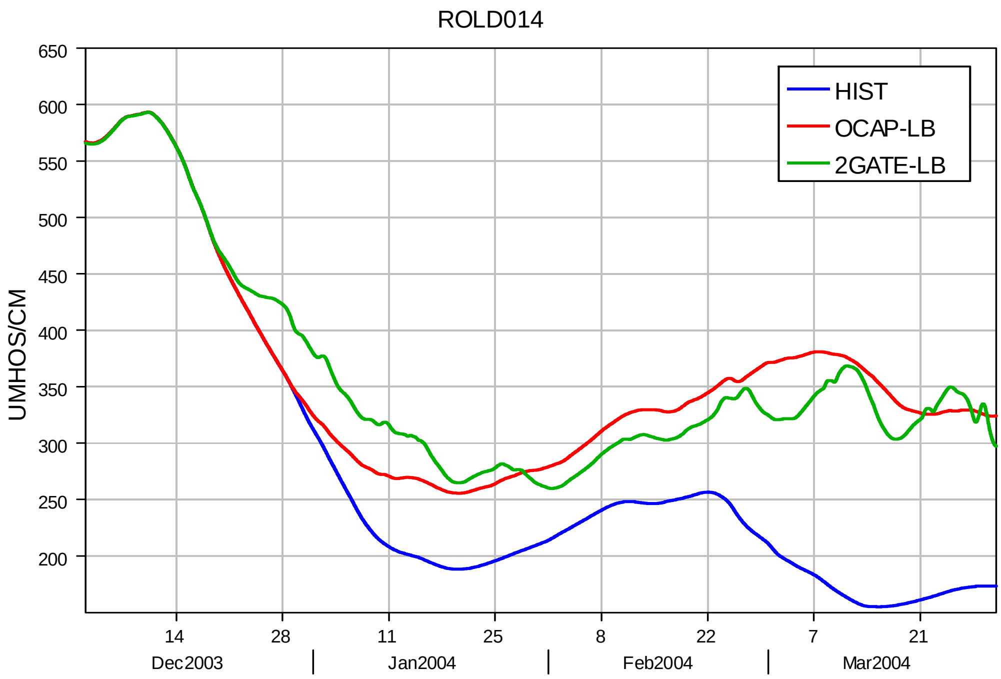


Figure 13 Tidally averaged EC at ROLD014 for the 2003-2004 historical, OCAP-LB and 2GATE-LB simulations.

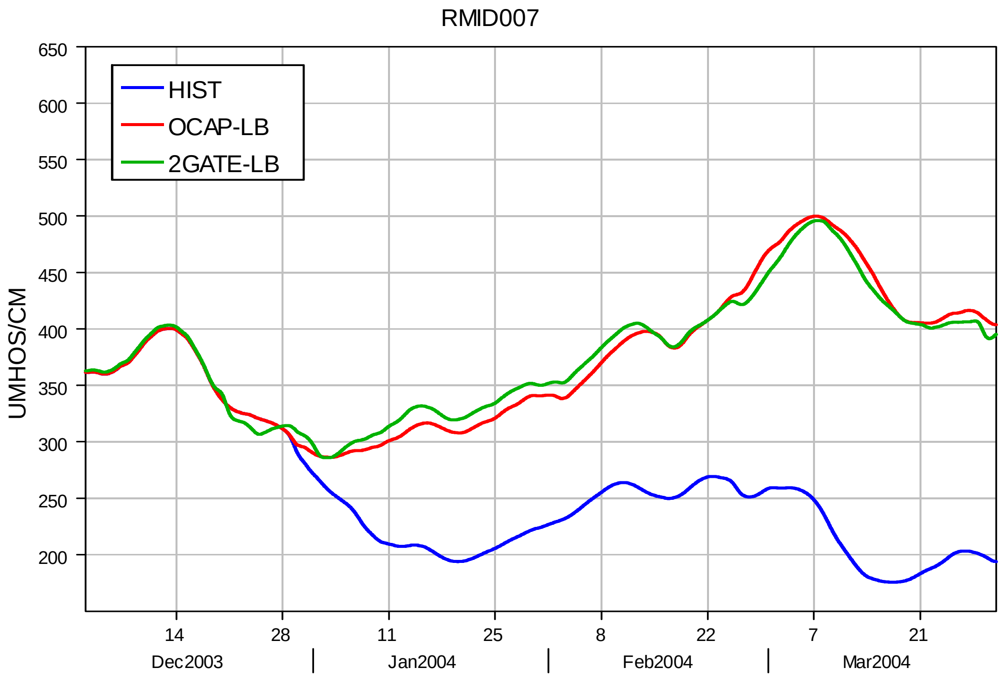


Figure 14 Tidally averaged EC at RMID007 for the 2003-2004 historical, OCAP-LB and 2GATE-LB simulations.

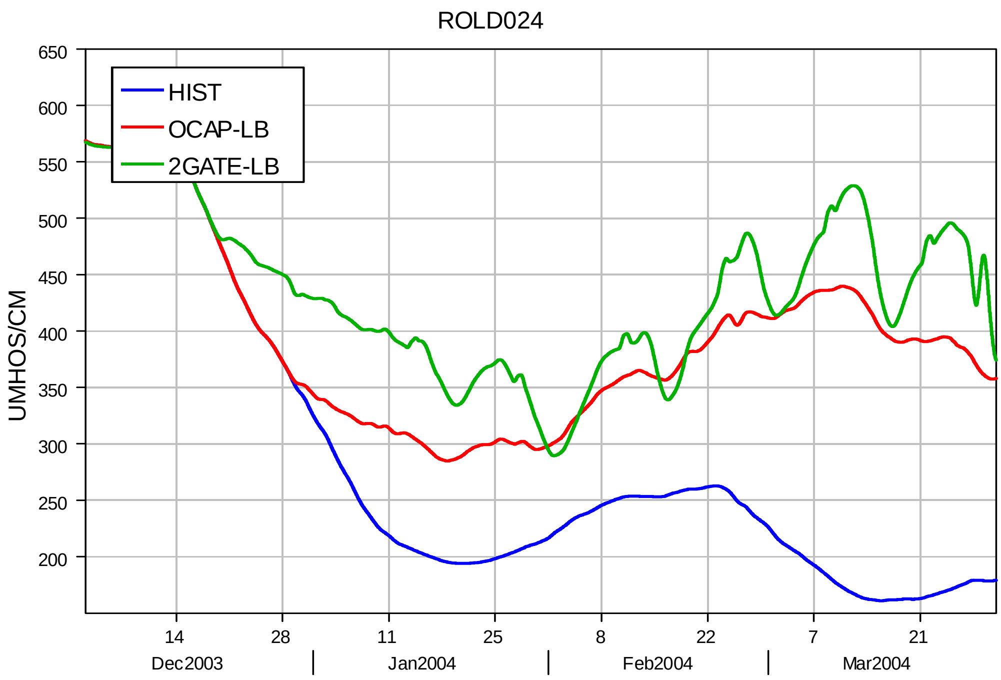


Figure 15 Tidally averaged EC at ROLD024 for the 2003-2004 historical, OCAP-LB and 2GATE-LB simulations.

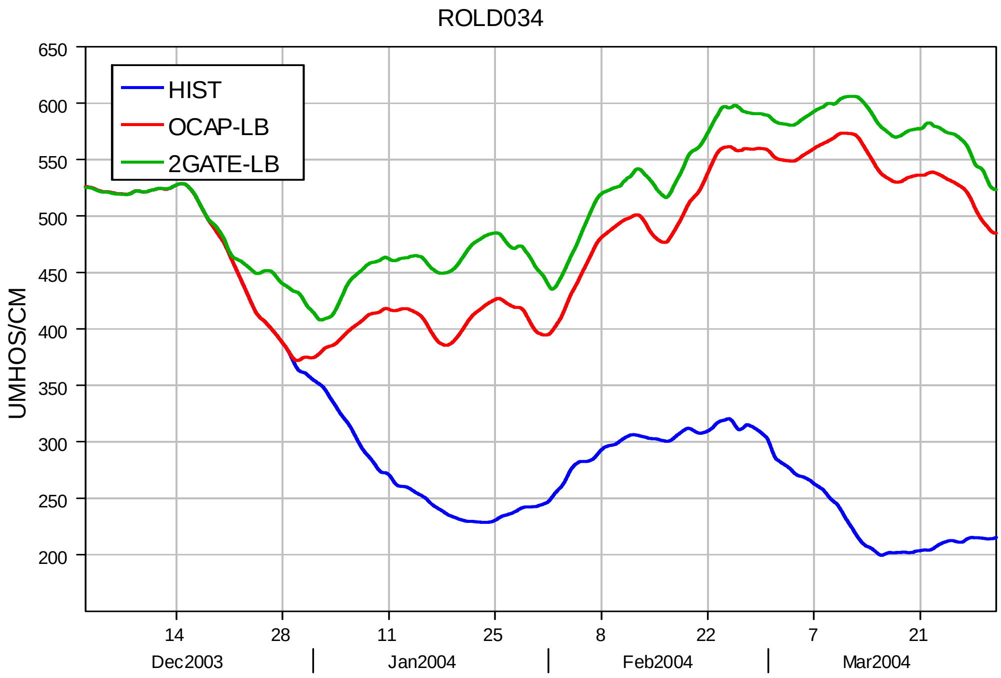


Figure 16 Tidally averaged EC at ROLD034 for the 2003-2004 historical, OCAP-LB and 2GATE-LB simulations.

Adult Smelt Simulations

Background

During the period of December through March, when adult delta smelt are moving upstream to spawn, there appears to be strong correlation between salvage of adult delta smelt at the state and federal export facilities and turbidity near the exports. A comparison of turbidity at Clifton Court and smelt salvage data at Skinner and Tracy illustrates this correlation. Figure 17 through Figure 20 show observed Skinner and Tracy adult delta smelt salvage data plotted with observed turbidity in Clifton Court and dynamic and tidally averaged computed turbidity in Old River just outside Clifton Court. In each case the peak salvage events coincide with periods of high turbidity. Most interestingly, in the December 2003 through March 2004 period (Figure 20) there were two spikes in turbidity and two corresponding spikes in adult delta smelt salvage. The Sacramento and San Joaquin River inflows provide two distinct sources of turbidity. At the entrance to Clifton Court under historic flow conditions with relatively high export pumping, the background turbidity is primarily driven by the Sacramento River turbidity plume. Large daily variations in turbidity occur when there is high turbidity water coming from the San Joaquin River along Grantline Canal. The salvage patterns are more strongly correlated to the Sacramento River turbidity.

Under the direction of Dave Fullerton and Curt Schmutte, MWD funded RMA to develop a particle behavior model that attempts to simulate the upstream movement of adult delta smelt and potential entrainment during this period. The behavior model works within the RMATRK particle tracking model, which is driven by the RMA Bay-Delta hydrodynamic and water quality model. The adult delta smelt behavior model is a work in progress and updates to the model algorithm will likely occur. In its current form the particle model has been shown to provide reasonable estimates of entrainment patterns for several historic years.

Adult Delta Smelt Behavior Model

The basic hypothesis of the behavior model is as follows. Adult delta smelt desire to move upstream from the Suisun Bay region during the late fall or early winter to spawn. The fish wait until the first storm events of the season increase the turbidity in the interior of the Delta. The fish prefer to avoid water with very low turbidity because of higher risk of predation and/or lack of food supply. The fish determine the desired direction of travel by sensing local gradients of salinity and turbidity. Initially, when they are in the Suisun Bay Region, the upstream direction is determined by a decreasing gradient of salinity. Once into the interior of the Delta where the salinity gradient is very small, the fish randomly explore the Delta channels to find suitable spawning habitat. If the turbidity is too low, the fish will move in the direction of increasing turbidity. If the turbidity gradient is too small however and it cannot be determined which direction leads to higher turbidity, the fish will hide.

Delta smelt are relatively small fish and not strong swimmers, so it is hypothesized that they will use a "surfing" mechanism with tidal flows to move though the Delta channels without expending a large amount of energy. In open channel flow, peak velocities are near the surface toward the middle of the channel, while near the bed or along shallow banks the velocity is very low. If a fish chooses to move with the tidal flow, it can easily move toward the surface where the velocity is highest. Conversely, if the fish chooses not to move with the tidal flow, then it can move toward the bottom where the velocity is very low. This allows the fish to ride the tidal flow in a preferred direction. For example, if the turbidity at the current location is too low and the fish desires to move toward more turbid water, it would tend to hold its position (move to the bottom) if the turbidity gradient along the direction of flow was such that the tidal flow was bringing higher turbidity water toward it. When the tide turned and flow directions reversed, the fish would move toward the surface to go with the tidal flow. Because tidal excursions in the Delta channels are quite large, often on the order of several kilometers, fish can move very quickly using this surfing mechanism.

The behavior model is implemented on top of the RMATRK particle tracking model. At each tracking step, the transport velocity is computed for a neutrally buoyant passive particle moving with the streamline velocity computed by the RMA Bay-Delta Model and subject to a random velocity component representing turbulent dispersion. Then the behavior model is used to determine an adjustment to the transport velocity. The behavior algorithm utilizes the local concentration and gradient of electrical conductivity (EC, simulated as a surrogate for salinity) and turbidity computed by the RMA Bay-Delta Model to determine the adjustment to the transport velocity.

The behavior algorithm is as follows.

- If the local EC is greater than the required maximum limit
    - Surf toward lower EC.
- Else if the local turbidity is lower than the required minimum limit
    - If the local turbidity gradient is greater than the minimum detectible gradient
        - Surf toward higher turbidity
    - Else if the local turbidity gradient is lower than the minimum detectible gradient
        - Hide
- Else if the local EC is lower than the desired minimum limit
    - Surf toward higher EC.
- If the local EC and local turbidity are within required limits
    - Randomly move (explore desirable habitat).

The surfing behavior is implemented by applying a scalar velocity factor to the transport velocity vector computed for neutrally buoyant particles. The velocity factors for moving with the tidal flow and resisting tidal flow are user defined constants. Reasonable limits for these factors are zero as a minimum and 1.2 as a maximum factor. Assuming a logarithmic vertical velocity profile the peak velocity is approximately 1.2 times the depth averaged velocity. Hiding is also implemented with a user defined scalar velocity factor, which causes the particles to move slowly or stop.

Random movement to explore desirable habitat is currently implemented as addition random mixing. When a particle is at a location where the EC is below the required maximum limit and the turbidity is above the required minimum limit a random velocity component is computed based on user defined dispersion coefficients in the longitudinal (streamline) and transverse directions. The velocity component is computed as

$$v_i = \sqrt{\frac{2K_i}{dt} * g}$$

where:

v_i is the velocity component in the longitudinal or transverse direction (m/s),

K_i is the user defined dispersion coefficient in the longitudinal or transverse direction (m2/s),

dt is the tracking time step (s), and

g is a randomly selected value from a normal Gaussian distribution with standard deviation of 1.0.

The user defined calibration parameters for the current implementation of the adult delta smelt behavior model are:

- Required maximum EC limit (umhos/cm)
- Required minimum turbidity limit (NTU)
- Minimum detectable horizontal turbidity gradient (NTU/m)
- Desired minimum EC limit (umhos/cm)
- Velocity factor for moving with tide flow
- Velocity factor for resisting tidal flow
- Velocity factor used when hiding
- Longitudinal dispersion coefficient (m2/s) for random exploration
- Transverse dispersion coefficient (m2/s) for random exploration

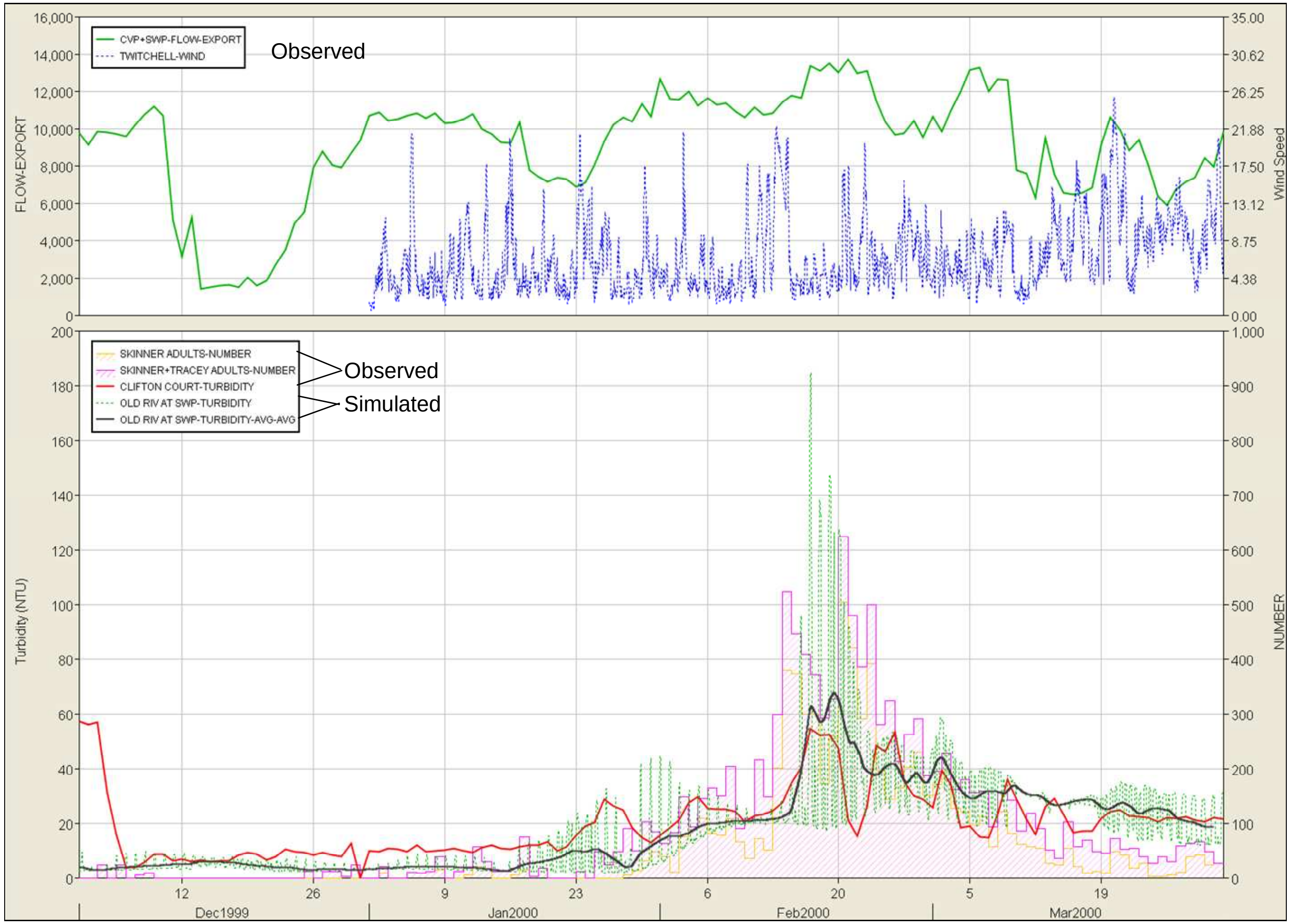


Figure 17 For December 1999 – March 2000: historical exports and Twitchell Island wind speed (above); and observed smelt salvage at Tracy and Skinner, observed Clifton Court turbidity, and computed dynamic and tidally averaged turbidity at the entrance to Clifton Court (below).

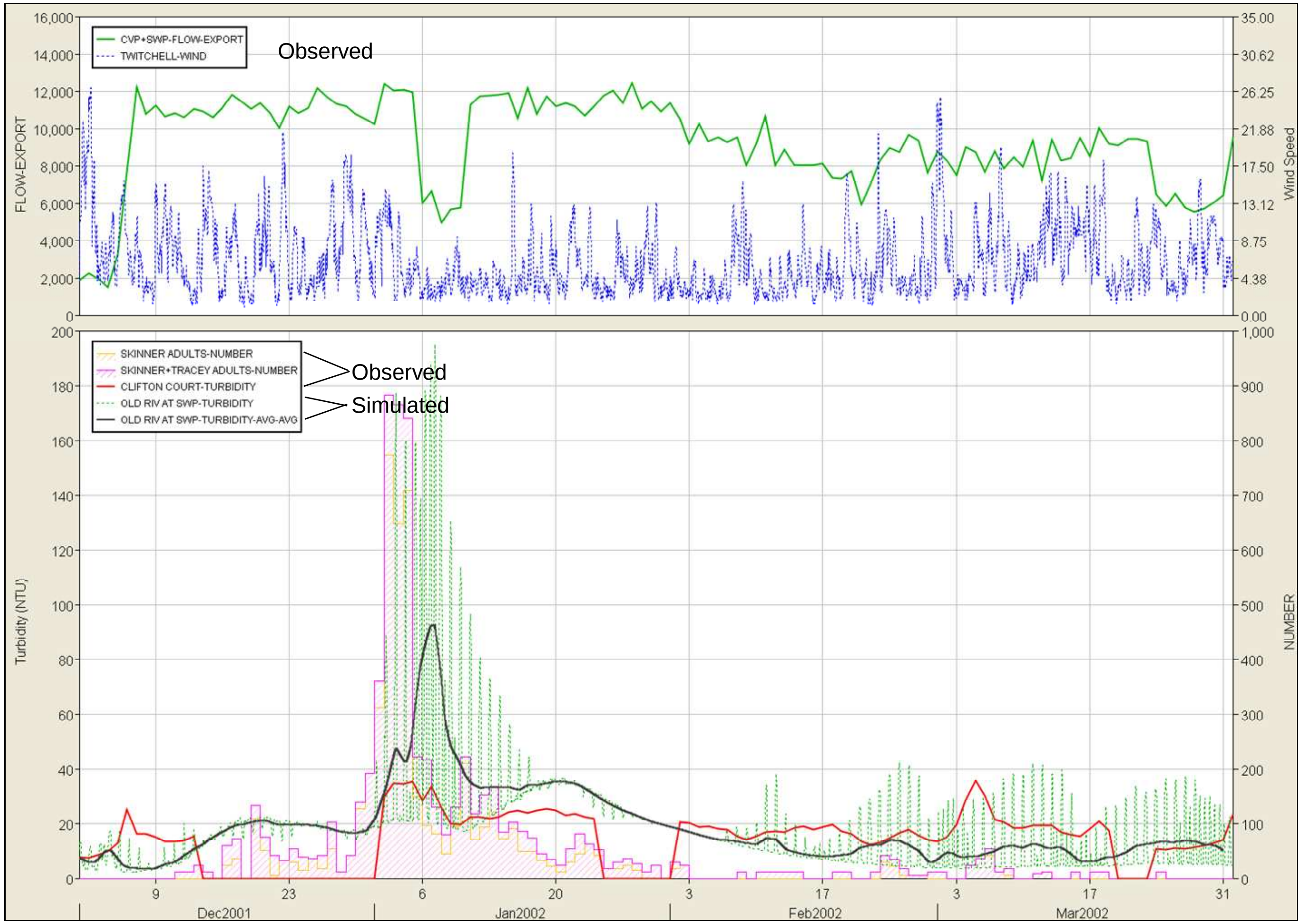


Figure 18 For December 2001 – March 2002: historical exports and Twitchell Island wind speed (above); and observed smelt salvage at Tracy and Skinner, observed Clifton Court turbidity, and computed dynamic and tidally averaged turbidity at the entrance to Clifton Court (below).

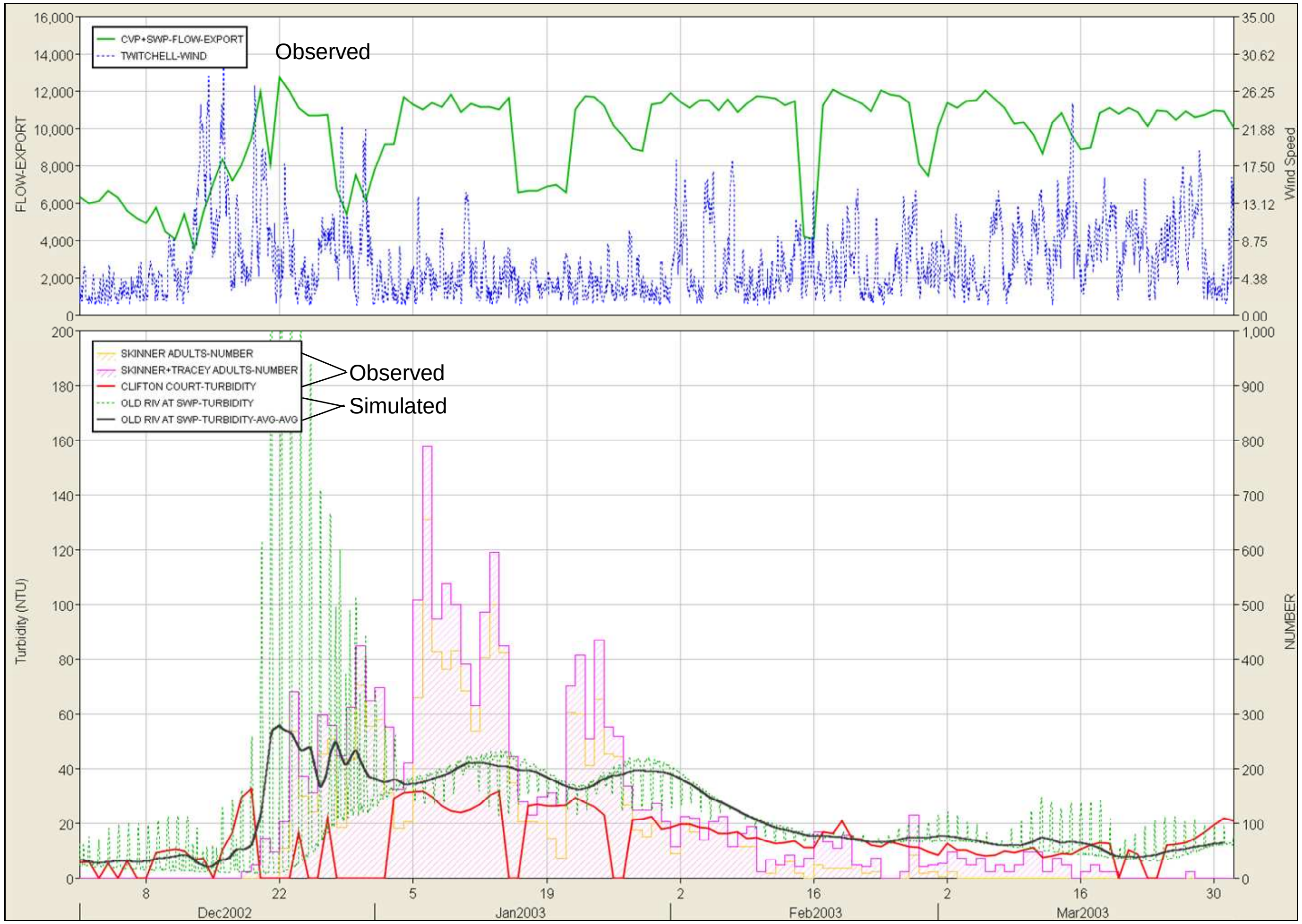


Figure 19 For December 2002 – March 2003: historical exports and Twitchell Island wind speed (above); and observed smelt salvage at Tracy and Skinner, observed Clifton Court turbidity, and computed dynamic and tidally averaged turbidity at the entrance to Clifton Court (below).

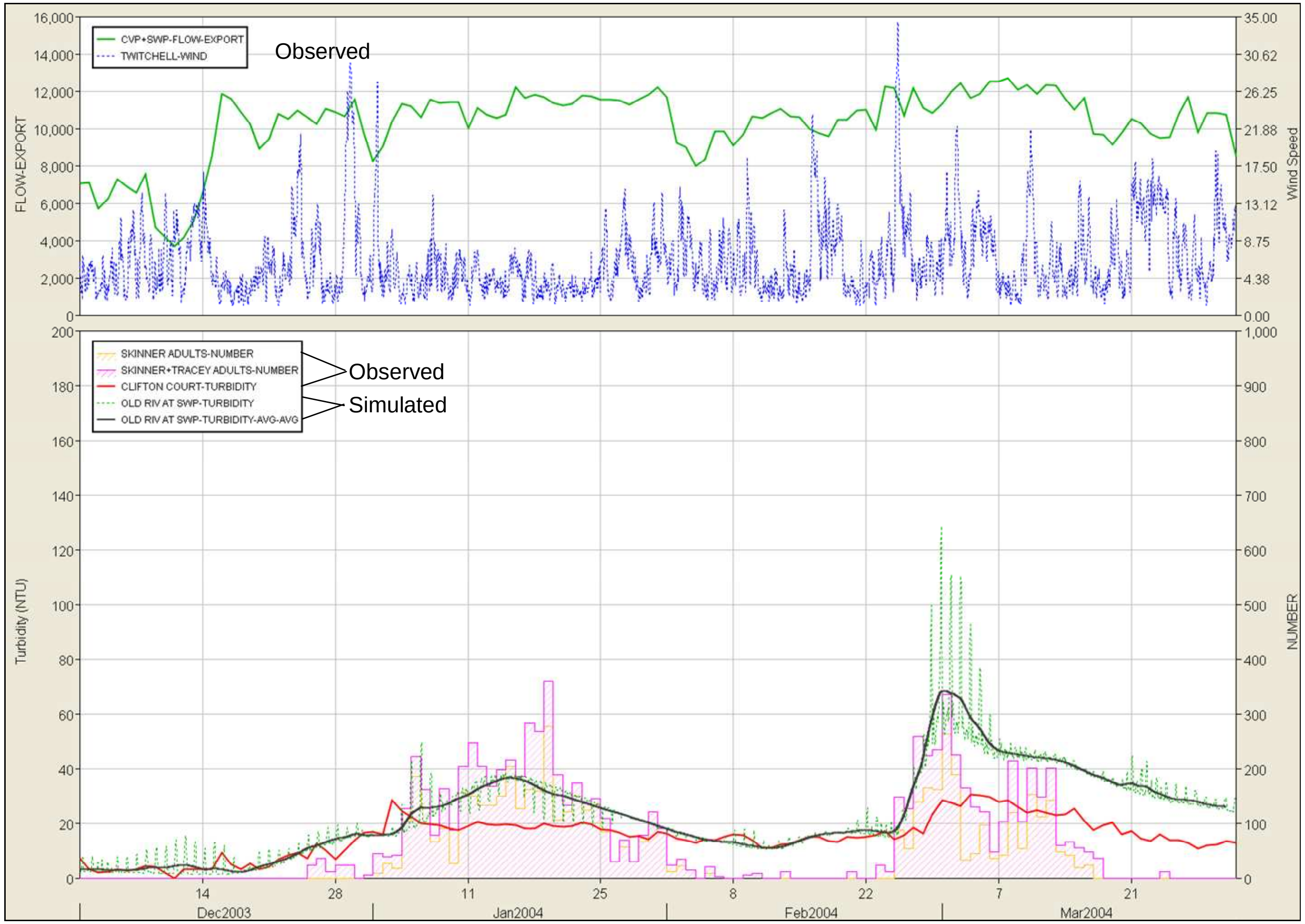


Figure 20 For December 2003 – March 2004: historical exports and Twitchell Island wind speed (above); and observed smelt salvage at Tracy and Skinner, observed Clifton Court turbidity, and computed dynamic and tidally averaged turbidity at the entrance to Clifton Court (below).

Model Calibration

In the current study, for each model simulation, 40,000 particles are dropped in Suisun Bay and a count is kept of the number of particles reaching the CVP and the entrance to Clifton Court. This number represents entrainment of model particles and must be scaled for comparison to salvage data.

To calibrate the model to observed salvage the total number of particles released was scaled up to the total population estimated by Rick Sitts (MWD) based on Kodiak trawl surveys. The value used was the averaged of the total population from all stations from the first two surveys of each year (Table 3).

Table 3 Summary of total smelt population based on trawl surveys.

Year	Total Delta Population (Average of Survey 1 and 2)
1999-2000	not available, estimated to be 1,000,000
2001-2002	1,355,000
2002-2003	992,000
2003-2004	1,212,000

Observed salvage is less than the total entrainment due to pre screen losses (predation for example) and screen efficiency. Salvage computed from particle entrainment as (total abundance estimate/total number of particles release)*screen efficiency * pre-screen losses * particle entrainment. There is considerable uncertainty in the estimates of pre screen losses and screen efficiency at both primary export locations. The uncertainty is particularly high for the Skinner facility at the State Water Project (SWP) due to the Clifton Court Forebay. Estimates for this work are shown in Table 4.

Table 4 Salvage factors at Skinner and Banks facilities.

Facility	Pre-Screen Loss	Screen Efficiency	Salvage Factor	Source
Skinner	75%	13%	(1.0-0.75)*0.13=0.0325	Kimmerer, 2008
Banks	15%	14.2%	(1.0-0.15)*0.142=0.1207	(Bowen, need ref)

Model parameters were adjusted manually to provide an approximate best fit of the entrainment pattern for the 2003-2004 simulation period that exhibited two distinct salvage peaks. The focus of the calibration was to match the timing of the initial salvage and timing of the peak salvage.

Table 5 Summary of factors and limits applied in the Adult Smelt model.

Maximum EC	1000 µmhos/cm
Minimum Turbidity	16 NTU
Turbidity Gradient Limit	0.0001 NTU/m
Desired minimum EC	150 µmhos/cm
Move with tide velocity Factor	1.2
Resist tide velocity factor	0.0
Additional Dispersion within region of acceptable EC and Turbidity	
Longitudinal Dispersion Factor	75 (m2/s)
Transverse Dispersion Factor	2 (m2/s)

Plots of computed and observed smelt salvage (Figure 21 through Figure 24) show that the model does a reasonable job of predicting smelt behavior. During 2000, the computed peak salvage occurs about two weeks earlier than observed, particularly at SWP and the overall numbers are lower. During 2001-2002, the peak is spread over a longer period than observed. In 2002-2003, the timing is fairly good, but the overall number at the SWP is lower than observed. During 2003-2004 the salvage is slightly earlier than observed at SWP and the peak at CVP is higher than observed. Overall, considering the uncertainties involved, the results indicate that useful estimates can be made with the model.

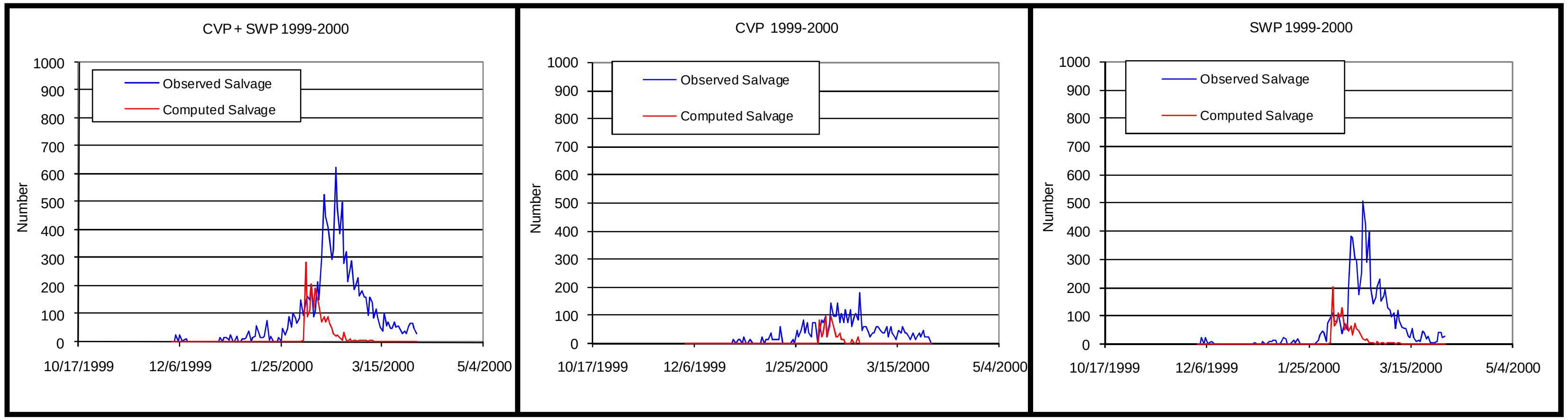


Figure 21 Observed and computed smelt salvage at the CVP and SWP exports during 1999-2000.

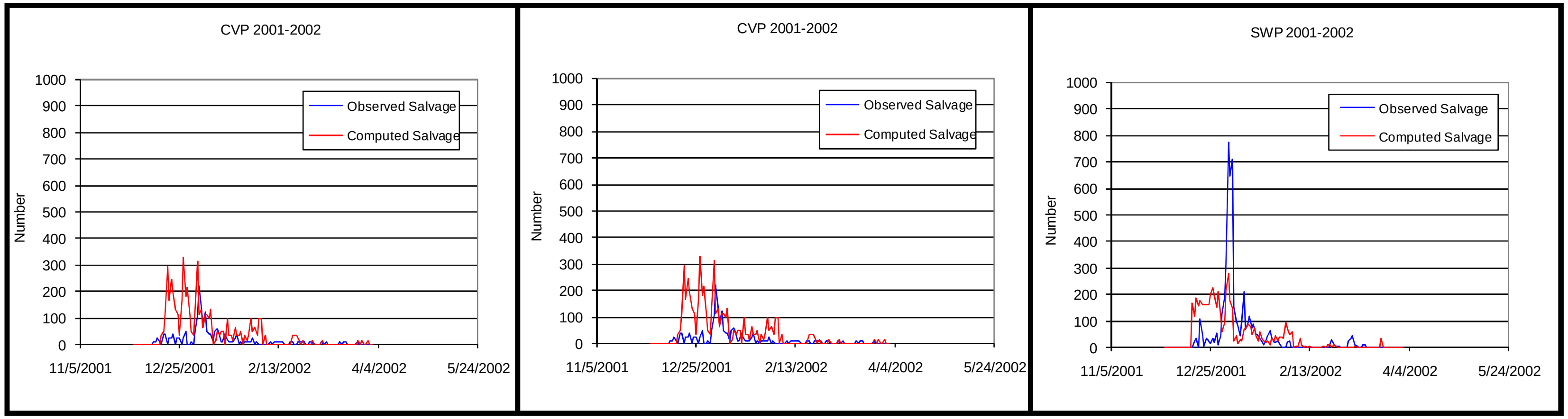


Figure 22 Observed and computed smelt salvage at the CVP and SWP exports during 2001-2002.

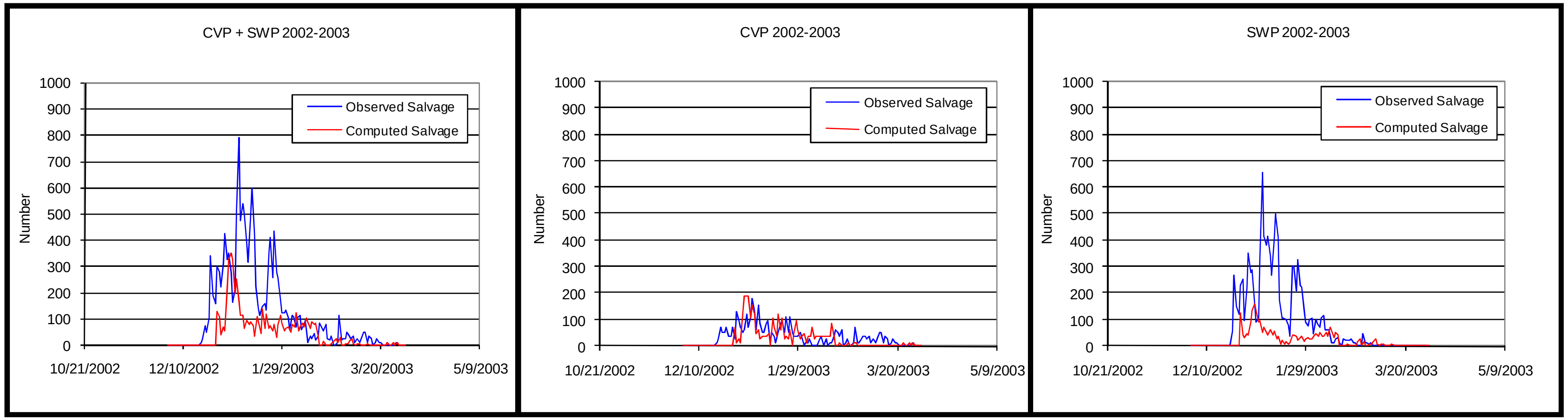


Figure 23 Observed and computed smelt salvage at the CVP and SWP exports during 2002-2003.

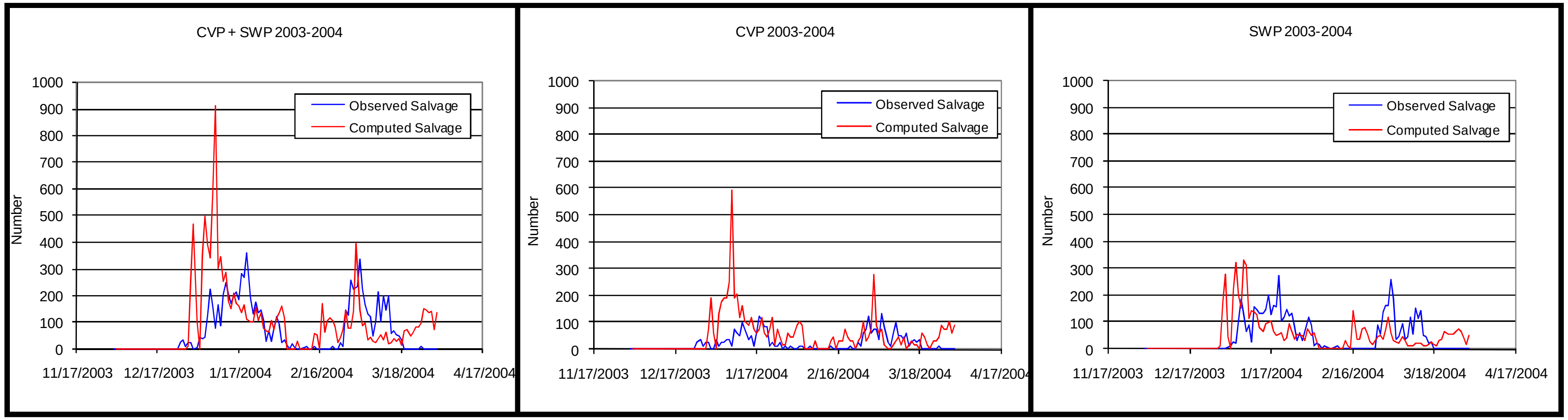


Figure 24 Observed and computed smelt salvage at the CVP and SWP exports during 2003-2004.

Limitations of Analysis

Given the relatively simple behavior hypothesis, the adult delta smelt model is providing a very encouraging comparison between observed and simulated salvage. The model is still in development, however, and it is important to bear in mind limitations of the current analysis.

The model is strongly dependent on the simulated turbidity distribution. The turbidity model is currently limited by lack of observed data for boundary conditions and it does not consider potential resuspension of sediments in large open water areas such as Franks Tract. Accuracy of the turbidity model for future periods would be greatly improved if observations where available for the Yolo Bypass, Mokelumne, Cosumnes, Calaveras inflows as well as Delta Island return flows. The during the turbidity model calibration work for 2007-2008, local spikes in turbidity were correlated to wind events. This information can act as a starting point for implementing a resuspension algorithm in the model.

The timing of initial adult smelt entrainment was calibrated by adjusting the lower limit of acceptable turbidity. Based on the simulated turbidity distribution, the calibrated limit value was 16 NTU. If additional information becomes available to improve the simulated turbidity distribution, the lower limit value of the behavior model may need to be adjusted. For example, if the current turbidity model is over predicting turbidity in the south Delta, then with an improved turbidity model the adult smelt behavior algorithm would be recalibrated and the lower turbidity limit would be smaller.

The model currently under predicts salvage for 1999-2000. The simulated turbidity during that period appears to be low. Having a better representation of Delta Island return flow turbidity and resuspension in Franks Tract may improve the model performance for that year.

Relating particle simulation to salvage has large uncertainty. The total Delta population estimate based on spots surveys has large uncertainty. The prescreen losses and screen efficiencies are also uncertain. Particularly the prescreen losses for the SWP are a problem due to the Clifton Court Forebay. Changes to these estimates would not, however, have a strong impact on the calibrated behavior model parameters because the calibration was focused on the pattern of salvage, and not the magnitude of the salvage.

The current behavior model uses a random dispersion component to represent exploration within the region of acceptable habitat. Perhaps a better way to represent that process is to use the tidal “surfing” mechanism in a random direction. Tests are currently underway using a “run and tumble” decision process for randomly choosing a tidal surfing direction as a replacement for the current random dispersion. If this method is successful, the desired lower salinity limit in the current algorithm may no longer be needed. The desired lower salinity limit acts to prevent particles from dispersing far up the Sacramento where, during the winter runoff period, salinity is very low. If a tidal surfing method was used for the random exploration particles would be prevented from moving far up the Sacramento River during high flow because the river is unidirectional downstream, so not lower salinity limit would be necessary.

Results and Discussion

The adult delta smelt particle tracking analysis was used to compare predicted cumulative entrainment between historic conditions, OCAP upper and lower bound conditions, and multiple variations of the 2-gate operations. The particle tracking simulations utilized the RMA Bay-Delta Model results for hydrodynamics, salinity (as EC), and turbidity for December through March of 1999-2000, 2001-2002,2002-2003, and 2003-2004 as described in a previous section of this document. A summary of the set of adult delta smelt simulations is presented in Table 6.

For each particle tracking simulation, 40,000 particles were released at the beginning of December. The particles were randomly distributed in the Suisun Bay Region. Through the course of the simulation period, the particles moved through the Delta based on the behavior algorithm described above. Particles were removed from the system only at the CVP and SWP exports. It was assumed for this analysis that losses of adult delta smelt were negligible for the Contra Costa Water District intakes on Old River and Rock Slough and for Delta island diversions.

The particle distribution over time closely follows the evolution of the turbidity distribution as storm flows from the Sacramento River and San Joaquin River move through the system. Figure 25 illustrates the particle distribution for four cases at the time of the first historic salvage peak in 2003. The four cases include Historic conditions, OCAP lower bound, OCAP lower bound with 2-gate Start time for OMR reduction, and 2-gate Balanced Operation. Figure 5 presents the corresponding simulated turbidity distribution for the same four cases. In each case the particles have spread through the Delta to the lower turbidity limit as specified in the calibrated behavior model. Under historic conditions, particles have moved down Old and Middle Rivers and entrainment is occurring at both export locations. Under the baseline OCAP condition, particles have moved down Old River close to the Clifton Court intake channel and some limited entrainment has occurred, but the particles have not moved far down Middle River. By starting the OCAP OMR flow restriction a little earlier (December 20 rather than December 23), particles did not progress as far down Old River, reaching just south of the junction with Indian Slough. With the 2-gate balanced flow operation, the turbidity is distributed more equally down Old and Middle River and consequently the particles have not moved as far down Old River and in the other cases. This results in reduced potential for entrainment.

Time series of combined entrainment at the CVP and SWP are presented as percent of total particles release in Figure 26 through Figure 32. In general, the OCAP flow restrictions provide significant reduction in entrainment for all years. The difference between the OCAP lower bound and upper bound is typically not important in these simulations because the peak adult entrainment occurs before the time when the Action 2 trigger allows the flow restriction to diverge from the Action 1 restriction of

-2000 cfs OMR flow to the lower bound of -1250 cfs OMR flow or the upper bound of -5000 cfs OMR flow. The exception is 2004 when entrainment is still occurring during the second turbidity peak in February and March (Figure 29). The 2-gate balanced operation typically provides an incremental reduction in entrainment beyond the OCAP baseline, often eliminating entrainment entirely. Cumulative entrainment results are summarized in Table 7.

A series of simulations were performed with the 2-gate balanced operation increasing exports so that the OMR flow ranged from -2000 cfs to -5000 cfs and was held constant through the end of March. Cumulative entrainment percentages for these runs are presented relative to the Historic condition and OCAP baseline upper bound run in Figure 31. While the cumulative entrainment with -4000 cfs and -5000 cfs OMR flow do exceed the OCAP baseline result, even with -5000 cfs OMR flow the 2-gate balanced operation cumulative entrainment is only 6% where the Historic entrainment is 19%. With constant -3000 cfs OMR flow the 2-gate balanced operation cumulative entrainment is 0.6%, significantly less than the OCAP baseline simulation with -2000 cfs OMR restriction.

Another sensitivity test was performed using 2004 conditions to compare the -3000 cfs OMR flow restriction with and with the 2-gate balanced operation (Figure 32). In this case the -3000 flow restriction was only used for the Action 1 period, then flow transitioned to the OCAP lower bound. Without the gate operation, entrainment was still lower than the OCAP baseline operation due to the early start of the OMR restriction. With the gate operation and a 3-day flow adjustment, entrainment was entirely eliminated in the simulation.

Table 6 Summary of Adult smelt model analysis simulations.

Simulation Name	Years Simulated	2 gates	RPA 1 trigger	RPA 1 OMR (cfs)	RPA 2 OMR (cfs)
HIST	All				
OCAP-LB	All		OCAP	-2000	-1250
OCAP-UB	All		OCAP	-2000	-5000
OCAP -2GST-LB	All		Jersey Pt	-2000	-1250
OCAP-3000-2GST -LB	All		Jersey Pt	-2000	-1250
2GATE-LB	All	✓	Jersey Pt	-2000	-1250
2GATE-UB	All	✓	Jersey Pt	-2000	-5000
2GATE-2000	2004	✓	Jersey Pt	-2000	Continue RPA 1
2GATE-3000	2004	✓	Jersey Pt	-3000	Continue RPA 1
2GATE-4000	2004	✓	Jersey Pt	-4000	Continue RPA 1
2GATE-5000	2004	✓	Jersey Pt	-5000	Continue RPA 1
2GATE-3000-LB	2004	✓	Jersey Pt	-3000	-1250
2GATE-4000-LB	2004	✓	Jersey Pt	-4000	-1250
2GATE-5000-LB	2004	✓	Jersey Pt	-5000	-1250
2GATE-3000MOD-LB	2004	✓	Jersey Pt	-3000*	-1250

*For 2GATE-3000MOD-LB simulation, exports were reduced briefly near the end of January to maintain positive Qwest at San Andreas Landing.

Table 7 Summary of cumulative percent of total particles released as of March 31 of each simulation year.

Simulation Name	Cumulative % of Total Particle Release				
	31-Mar-2000	31-Mar-2002	31-Mar-2003	31-Mar-2004	31-Mar-2008
HIST	4.6	13.6	10.3	19.2	11.2
OCAP-LB	0.0	1.4	0.8	1.1	2.1
OCAP-UB	0.02	1.4	1.0	2.5	2.4
OCAP -2GST-LB	0.0	0.0	0.3	0.0	0.3
OCAP-3000-2GST -LB	--	--	--	0.4	--
2GATE-LB	0.0	0.0	0.0	0.0	0.0
2GATE-2000	--	--	--	0.0	--
2GATE-3000	--	--	--	0.6	--
2GATE-4000	--	--	--	3.5	--
2GATE-5000	--	--	--	5.9	--
2GATE-3000-LB	--	--	--	0.2	--
2GATE-3000MOD-LB	--	--	--	0.0	--

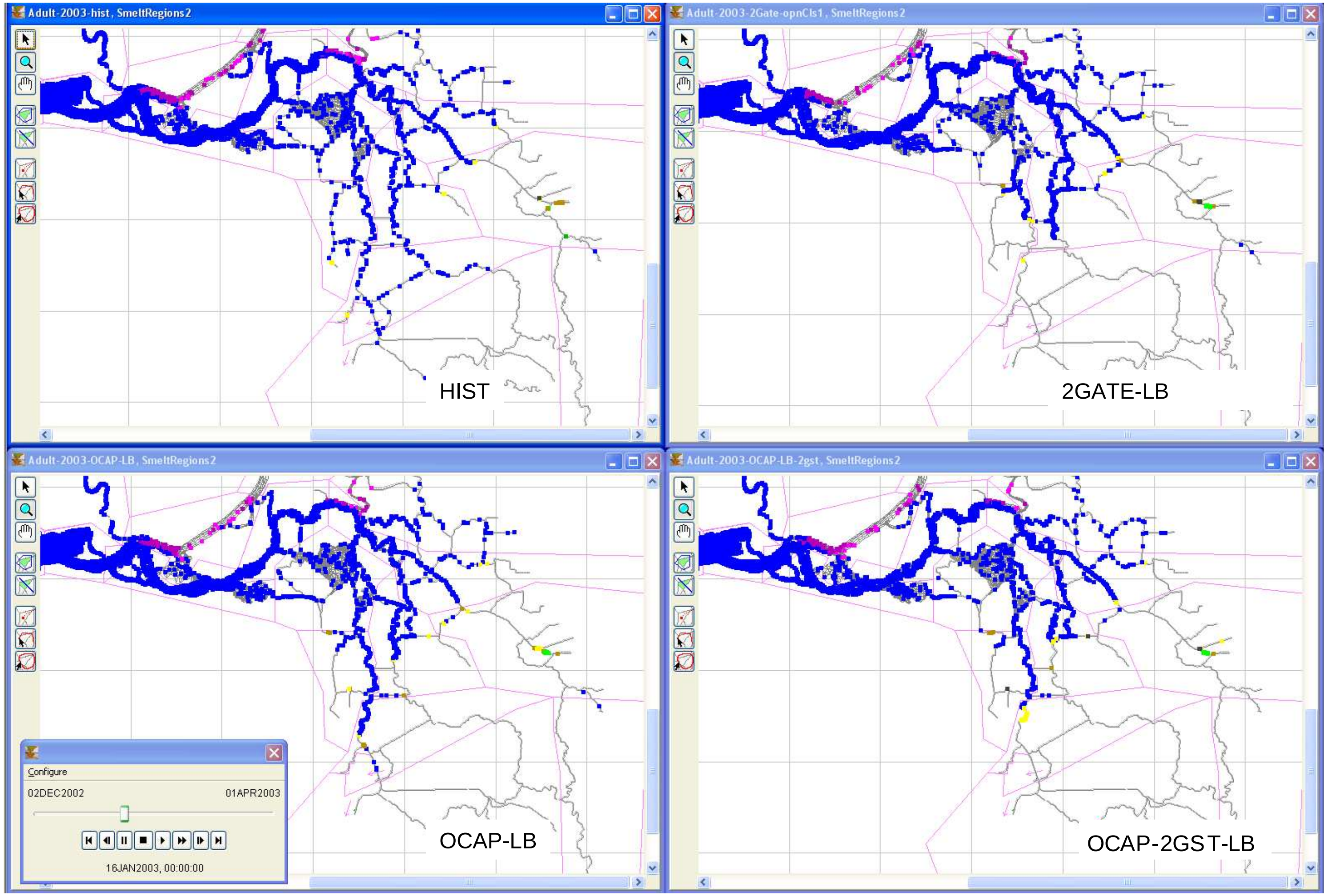


Figure 25 Adult Delta Smelt Particle Distributions for historical conditions, OCAP operations, 2-gate scenario, and OCAP operations with 2-gate start time (OCAP-2GST) on 16 Jan 2003 at 00:00.

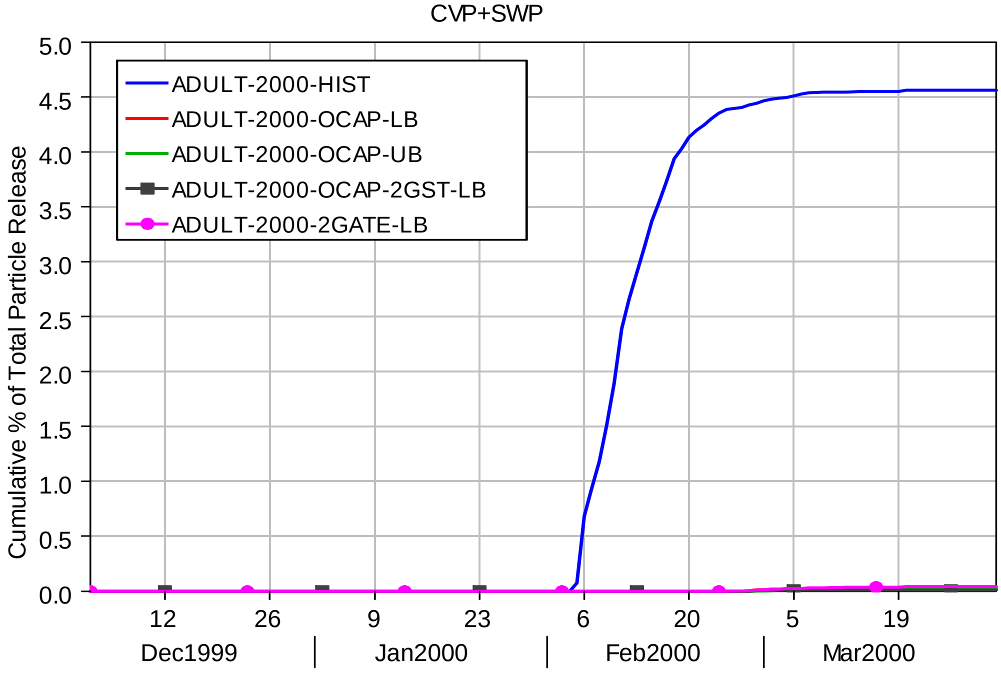


Figure 26 Cumulative entrainment as percent of total particles released at the CVP and SWP export locations, December 1999 through March 2000.

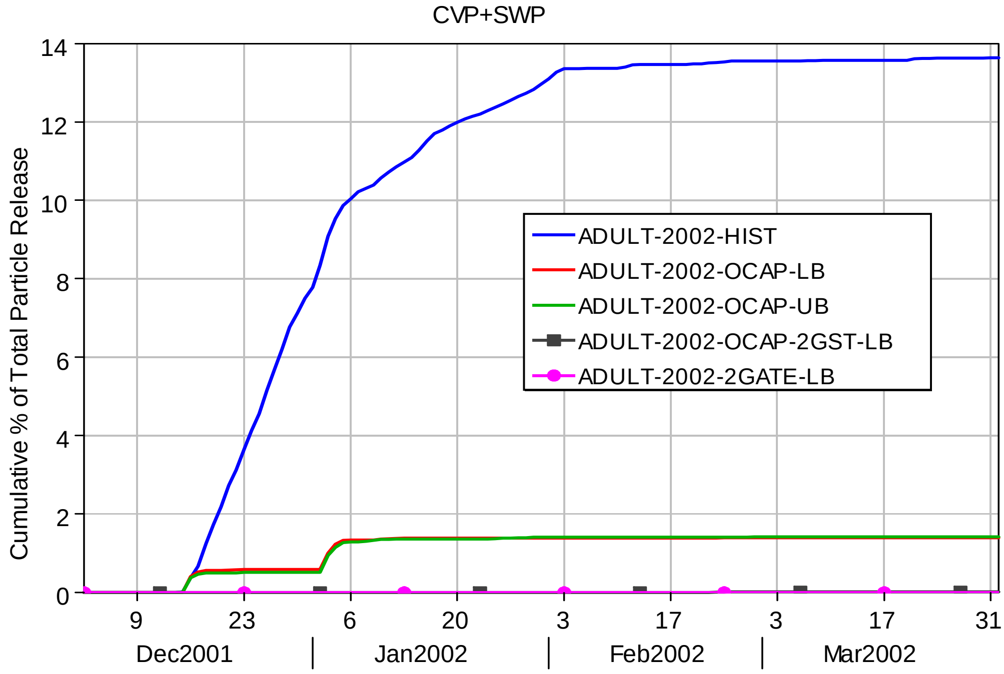


Figure 27 Cumulative entrainment as percent of total particles released at the CVP and SWP export locations, December 2001 through March 2002.

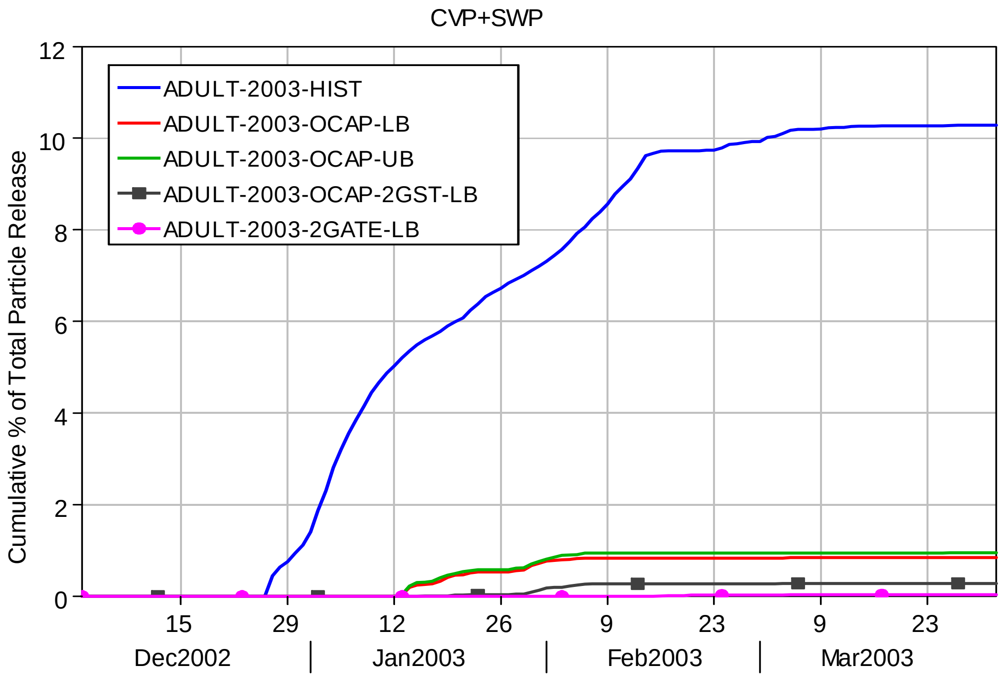


Figure 28 Cumulative entrainment as percent of total particles released at the CVP and SWP export locations, December 2002 through March 2003.

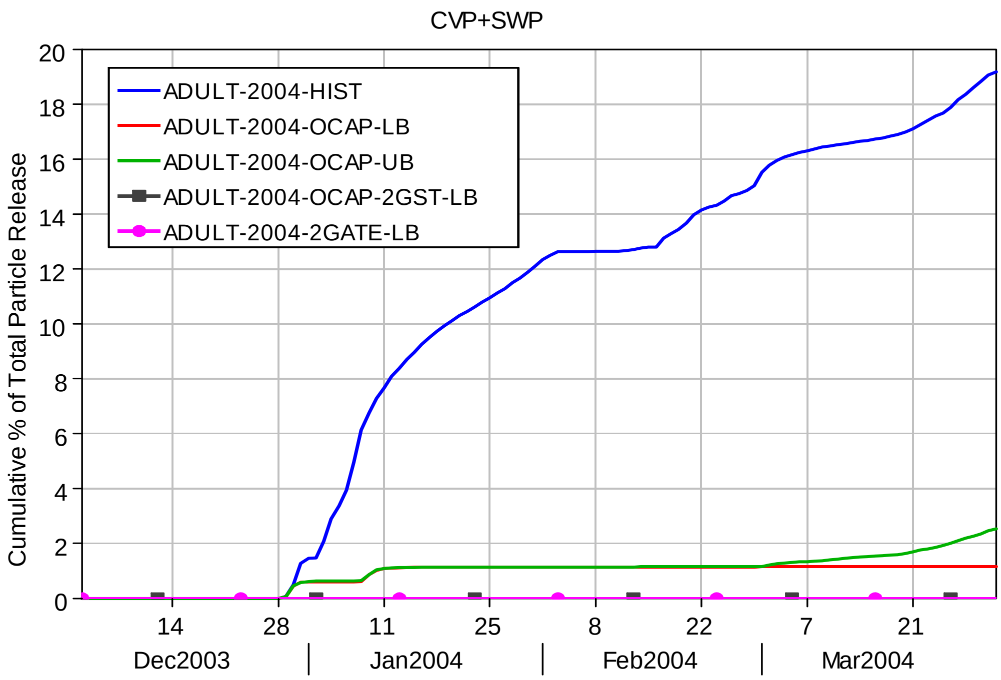


Figure 29 Cumulative entrainment as percent of total particles released at the CVP and SWP export locations, December 2003 through March 2004.

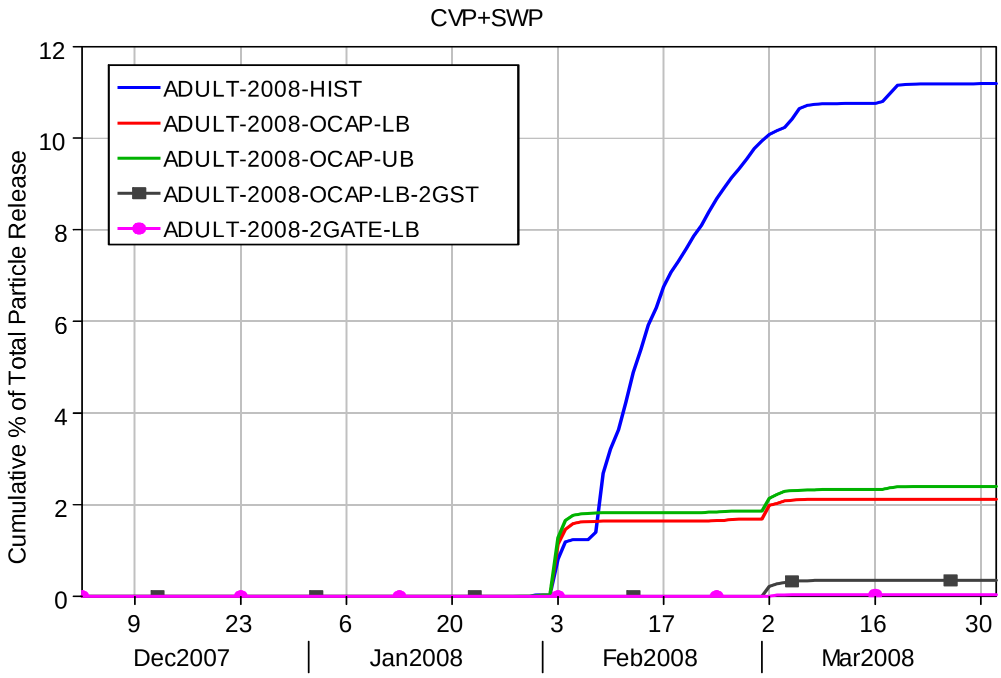


Figure 30 Cumulative entrainment as percent of total particles released at the CVP and SWP export locations, December 2007 through March 2008.

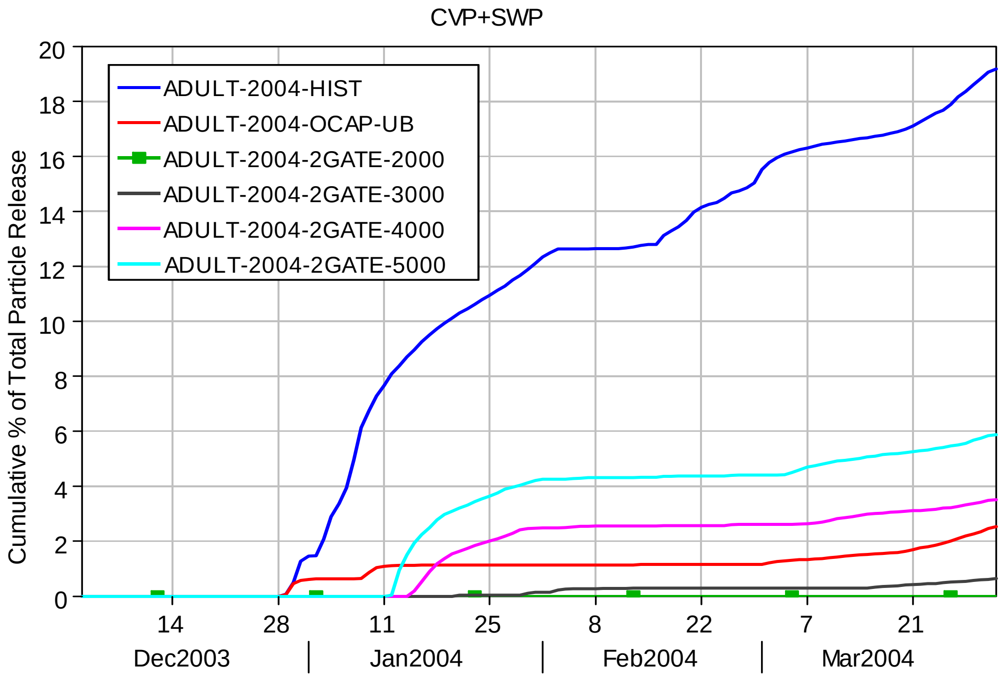


Figure 31 Cumulative entrainment as percent of total particles released at the CVP and SWP export locations, December 2003 through March 2004, with alternative OMR flow limits .

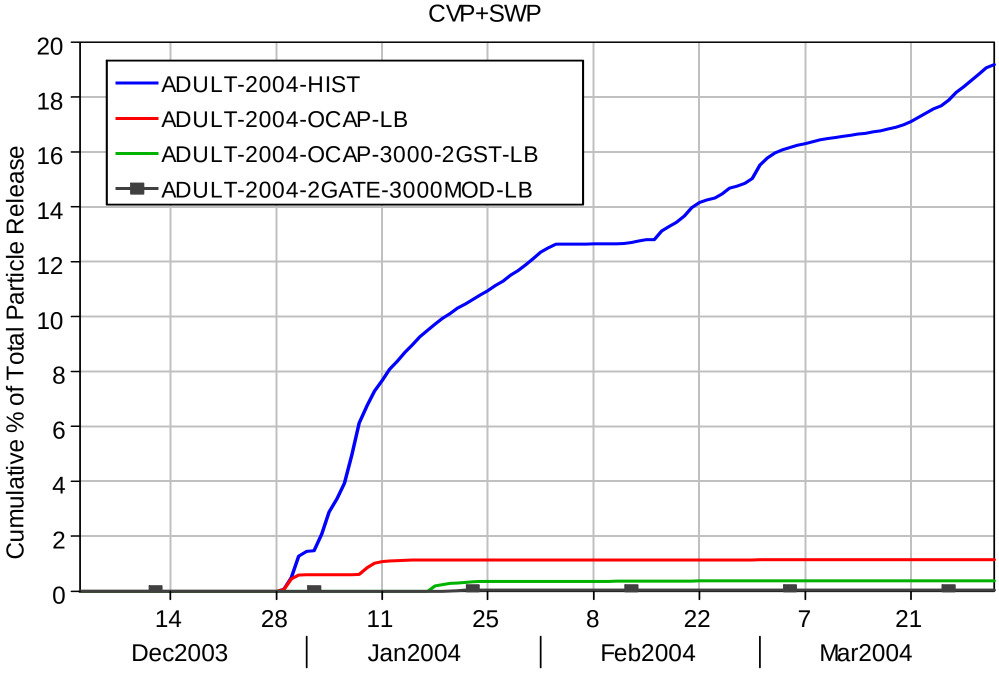


Figure 32 Cumulative entrainment as percent of total particles released at the CVP and SWP export locations, December 2003 through March 2004, with -3000 cfs OMR flows during RPA1 and lower bound flows during RPA2. For the 2-gate case, exports were reduced briefly near the end of January to maintain positive Qwest at San Andreas Landing.

Larval/Juvenile Smelt Simulations

The objective of this analysis is to objectively estimate the delta smelt hatching distribution that is, by some metric, most consistent with available observations of delta smelt distribution and salvage. Both historic and scenario simulations use the RMA Bay-Delta Model and RMATRK for passive particle tracking. A post-processing tuning analysis is used to estimate regional hatching rates which are used to scale the raw particle tracking results to best match observed fish distributions. The observations employed in the tuning analysis include 20mm survey observations and CVP salvage observations. The post-processing approach to estimate hatching and mortality developed by Edward Gross and Lenny Grimaldo (USBR) has been extended and applied to this analysis. The "engine" of the tuning method is the differential evolution algorithm (Price and Storn, 1997).

The hatching rates estimated for historic conditions will be applied without modification to the various operations scenarios. Therefore the effect of the revised operations on delta smelt hatching rate and distribution will not be reflected in the simulation results. The simulations will focus on the effect of the operations on delta smelt distribution and fate after the initial hatching occurs.

Historical RMATRK Simulations

The RMATRK model was applied to simulate particle transport for the larval and juvenile delta smelt period in 5 historical periods: 2000, 2002, 2003, 2004 and 2008. 1999 was also simulated to compare with previous simulations performed with the UnTRIM hydrodynamic model and the FISH particle tracking model. Each simulation began on February 15th and extended through July 15th. At the beginning of the simulation, no particles were present. Particles were released and tracked by source region (Figure 33) with a total of 27 source regions included in the model domain. The regions are related to regions used in previous delta smelt distribution and abundance analyses (Miller, 2005). However, some regions were subdivided to allow increased resolution of variability in delta smelt density. In each region particles were released at a two hour interval at a specified release density (fish$m^{-2}day^{-1}$). The location of all particles was output at a two hour interval over the simulation period. For each particle entrained by the CVP or SWP, the time of entrainment was recorded.

Analysis of 20mm Survey Observations of Delta Smelt

The 20mm survey observations were analyzed to estimate regional density and Delta population of delta smelt. A logistic function for capture probability (Kimmerer and Nobriga, 2007) was used to account for net efficiency in order to estimate the density of fish from the reported catch and fish length information. The fish density at the station locations was then interpolated onto a high-resolution model grid (MacWilliams et al. 2008) and the interpolated densities were volume averaged in each region to calculate regional-averaged density. A rough estimate of abundance is the sum of the number of fish in each region, where the estimated number of fish in each region is calculated as the product of the fish density in that region and the region volume. Maps of the interpolated (cell) density and regional averaged density have been generated for each survey from 1995 through 2008.

Hatching Period Analysis

The hatching period was specified in each region according to temperature thresholds. The spawning period was assumed to begin when the 5 day trailing average temperature exceeded 12 C and a time lag of 9 days between the beginning of spawning and the beginning of hatching was assumed. The spawning period was assumed to end when the 5 day trailing average temperature exceeded 20 C and a time lag of 5 days between the end of spawning and the end of hatching was assumed.

Post-processing of Historical RMATRK Simulations

The particle locations calculated by the RMATRK model were analyzed in a post-processor to count the number of particles from each source region that are located in each analysis region (Figure 33) at each 2 hour output interval. Only particles released within the specified hatching periods were counted. Furthermore the particle counts were weighted by mortality factors according to the "age" of the particle, calculated as the time elapsed from the release (hatching) of the particle. Five different mortality rates were applied to each set of simulation results: 0.0 day^{-1}, 0.02 day^{-1}, 0.03 day^{-1}, 0.04 day^{-1}, 0.05 day^{-1}.. The mortality formulation and rates corresponded to the formulation and the range of values in Kimmerer (2008).

Tuning of Hatching Rates

An automated tuning approach is used to estimate the hatching rate in each region. Each regional hatching rate is constant in time during the hatching period specified based on the analysis of temperature data.

The regional hatching rates were tuned to minimize a cost function which was defined as the sum of two terms. The first term is the l_1 error norm in the comparison of regional averaged predicted and observed density and predicted and estimated density immediately upstream of the TFCF. The density estimated from salvage observations was calculated assuming pre-screen losses of 15% and whole facility efficiency of 14.2% through May 15 and 38.9% after May 15 (Mark Bowen, personal communication). Only fish longer than 20mm were counted as part of the predicted salvage. The initial size of the delta smelt is assumed to be 5.25 mm and the growth rate is 0.35 mm/day (Bennet, 2005), so 42 days from hatching are required to reach a length of 20mm.

The salvage observations were used in the tuning approach only from April 15th to June 30th of each year. This period was chosen as a rough approximation of the period when most fish salvaged are juvenile delta smelt and before the assumption of passive transport (no behavior) becomes clearly unrealistic. The second term in the cost function is the absolute value of the bias in Suisun Bay and Delta-averaged density. The inclusion of this second term in the cost function improves the comparison between predicted delta smelt "population" and estimated delta smelt "population."

The tuning algorithm is the differential evolution algorithm (Price and Storn, 1997) which is a general optimization algorithm used in many different applications. This algorithm is automated and does not require any subjective judgment after the cost function is specified. Therefore, the hatching rates are objectively selected as the rates that minimize the specified cost function.

The tuning analysis was performed independently for each year and each mortality rate. The mortality rate was chosen somewhat subjectively as a rate which gave one of the best “scores” in terms of minimizing the cost function and gave a good order of magnitude comparison in terms of the total number of fish salvaged at the TFCF during the simulation period. The mortality rate of 0.02 day^{-1} was used for all years. In general, the “score” was similar for all mortality rates, though higher mortality rates (0.04 day^{-1} through 0.06 day^{-1}) gave slightly better “scores” for some years. The lowest mortality rates (0.0 day^{-1} and 0.02 day^{-1}) gave the best comparison to observed TFCF salvage during some years.

Limitations of Analysis

The largest limitation of the analysis may be the limited accuracy of estimated regional densities from the 20mm survey observations. Due to the typically low numbers of delta smelt caught in a tow, the catch at any one station varies substantially from survey to survey. Furthermore, the overall density estimates can be very sensitive to a small number of fish caught due to the large “scaling” introduced by the logistic function which approximates the variation of net efficiency with fish length.

The salvage efficiencies and pre-screen losses at the TFCF are also highly uncertain. The values applied in the analysis were specified by Mark Bowen (personal communication) but may substantially underestimate some losses of smaller delta smelt in the TFCF (Brent Bridges, personal communication). The pre-screen losses of 15% are a “best guess” that has been used in previous analyses (Pete Smith, personal communication).

The use of constant hatching rates is a rough approximation but introducing additional complexity of time variable hatching to the tuning process was not feasible for this project. The hatching periods specified based on temperature observations were also quite approximate. In fact many of the largest errors in the predicted delta smelt distribution often occurred in the early surveys or soon after the end of the hatching period, suggesting that the specified hatching periods were not precise. Further analysis of 20mm observations should provide improved estimates of hatching periods.

The representation of mortality is also highly approximate. The mortality rate is treated as both spatially uniform and constant in time. It is likely that mortality rate varies strongly both spatially and with the life stage of delta smelt.

The current tuning approach provides little insight to the possible range/uncertainty of hatching in each region. This limitation is particularly notable in the regions with an estimated hatching rate of zero. A Bayesian analysis would provide the full range of possible hatching rates in each region and distinguish regions with highly uncertain hatching rates from regions where the hatching rates can be determined with some precision.

Results of Analysis

Hatching rates were estimated for each historical period. In addition, observed and predicted regional density was compared for each survey in each historical period.

Many observed trends in delta smelt distribution and abundance were reproduced by the tuned particle tracking approach. For example, the observed regional densities averaged in time across all 20mm surveys was predicted fairly well by the tuned particle tracking approach for all years. The hatching distributions for 1999, 2000 and 2004 all appear to be realistic in broad terms. In these years the approach predicts a fairly broad distribution of hatching with substantial hatching in the western Delta and north Delta. Some of the finer structure of the predicted hatching distribution is questionable in these years, including the sometimes large variability in hatching rates of adjacent regions. However, in the other years, hatching distributions do not appear to be realistic. In 2002, 2003 and 2008, the estimated hatching in most regions is zero and the region to region hatching variability is very large. In addition, the predicted central Delta hatching rates are almost uniformly zero in these years, which is inconsistent with the predictions for other years with more reliable/consistent observations.

The likely reason for the unrealistic estimated hatching rates in some years is the large variability in observed regional density among surveys.

Table 8 Summary of Larval/Juvenile smelt model analysis simulations.

Simulation Name	Gate operations	RPA 1 trigger	RPA 1 OMR	RPA 2 OMR
HIST	--	--	--	--
OCAP-LB	--	OCAP	-2000	-1250
OCAP-UB	--	OCAP	-2000	-5000
2GATE-OPT2-LB	Connection Sl closed, Old River open on ebb	Jersey Pt	-2000	-1250
2GATE-OPT2-UB	Connection Sl closed, Old River open on ebb	Jersey Pt	-2000	-5000

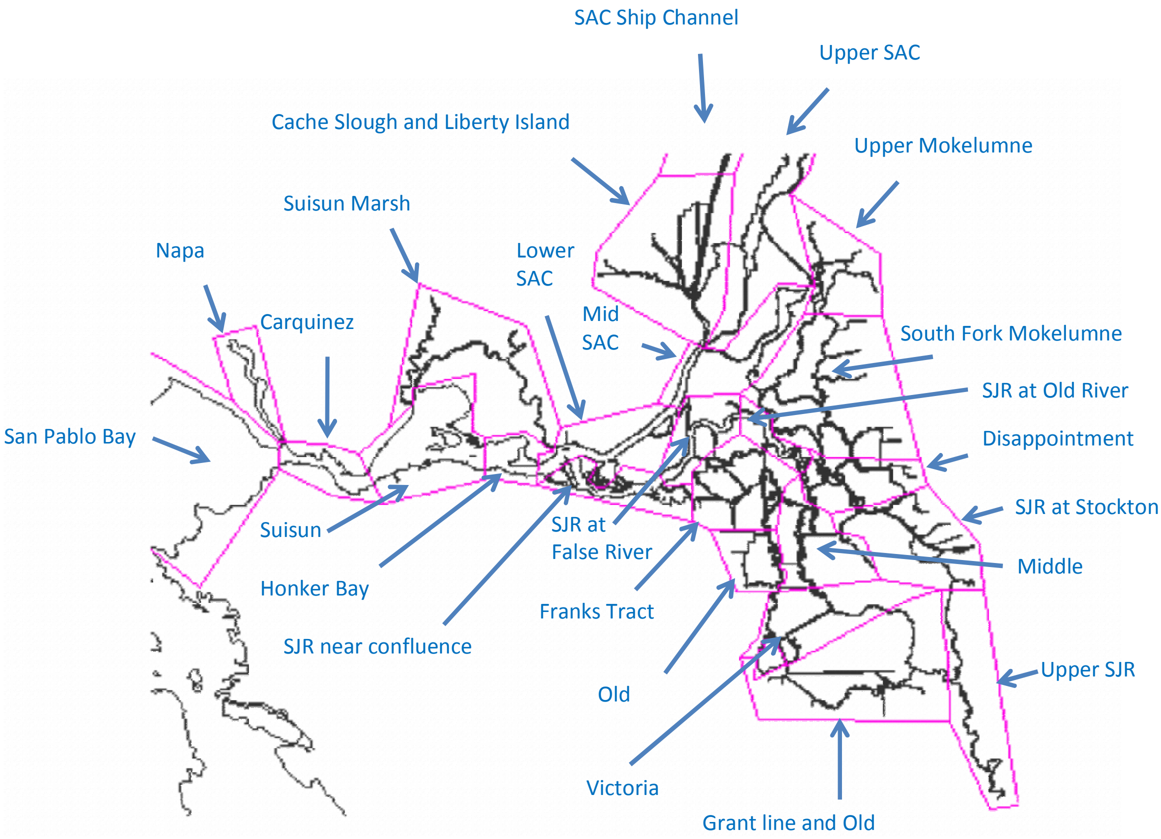


Figure 33 Source regions.

Discussion of Results for 2000

The observed regional densities for surveys 1 through 7 in 2000, determined by spatial averaging of observations at 20mm survey stations, are shown in Figure 35. The observed densities vary strongly, both spatially and temporally, with many regions showing zero density due either to a lack of sampling (no stations sampled) or zero catch at all stations sampled. In the many regions in which no stations were sampled, the density is unknown and, therefore, the tuning approach does not attempt to match those regions.

The hatching rate distribution determined by the tuning approach to best match available observations is shown in Figure 37. This hatching rate distribution is strongly variable spatially with the largest hatching rate in the Mid Sacramento region.

The observed and predicted regional densities averaged across surveys 1 through 7 are shown in Figure 38. This figure suggests that the average distribution through the simulation period is predicted quite well. In Figure 36, the predicted regional densities are shown for each region from survey 1 through 7. The predicted regional densities show a more persistent spatial and temporal pattern than the observed regional densities. In general, densities increase in most regions during the hatching period and then decrease due to mortality after hatching ends

The observed and predicted daily CVP salvage at the Tracy Fish Facility from April 15, 2000 to June 15, 2000 is shown in Figure 39. The predicted magnitude of entrainment is lower than the observed salvage. In addition, some “noise” may be present in the predicted salvage due to the finite number of particles used in the simulation resulting in a relatively small number of particles with age corresponding to length greater than 20mm that arrive at the Tracy Fish Facility each day.

In 2000 the gate operations have a larger effect on predicted delta smelt density than the OCAP flow restrictions. In all scenarios, high predicted fish densities are present in the Sacramento Ship Channel region due to high hatching rates estimated by the tuning method and long residence times in this region. The largest estimated regional hatching rate is the Mid Sacramento region hatching rate of 0.04 fish m^{-2} day^{-1}, though the predicted densities are moderate due to limited residence time in this region. The results for all scenarios are strongly influenced by this hatching distribution because the source of most fish is the north Delta.

In 2000, and other simulation periods, the results can be understood largely in terms of effects on distinct flow corridors. One flow corridor of interest is from the north Delta through the Delta Cross Channel and Georgiana Slough, then through the San Joaquin River, Old River and, eventually, Middle River. We will refer to this corridor as the “Middle River corridor.” While the reduced flows in OCAP reduce the flows through this corridor, the gate operations increase flows along this corridor by making Middle River flows more negative and Old River flows less negative or more positive. This can be seen in plots of Middle River and Old River flows for 2000, shown in Figure 40 and Figure 41. During 2000, the predicted densities along the Middle River corridor are not significantly altered as a result of OCAP. In contrast, the predicted densities are generally increased along this corridor by the gate operations which make flows more negative (see Figure 40), and therefore pull more fish from the north Delta into this corridor.

In contrast, both the OCAP flow reductions and the gate operations make flows on the Old River less negative, as shown in Figure 41. Therefore fewer particles/fish are drawn from Franks Tract and the San Joaquin near Old River under these scenarios than the historical scenarios. The Old River region shows slight decreases in the predicted fish density as a result of OCAP flow limitations. The predicted densities are decreased more substantially as a result of the optimized gate operations. Both Middle River, where density is increased as a result of gate operations, and Old River, where density is decreased as a result of gate operations, serve as transport corridors to the “far” south Delta, represented by the Victoria region and the Grant Line and Old region. The gate operations make the Middle River corridor the dominant corridor of transport to the “far” south Delta. The net effect of the gate operations in the Victoria region and the Grant Line and Old region is decreased density, because the densities along the Middle River corridor are lower than the densities along the Old River corridor.

The decreased predicted density in these south Delta regions results in decreased predicted entrainment (Figure 44). The number of particles from each source region that are entrained is shown in Figure 42. In regions with non-zero hatching the variability of predicted fish entrainment among scenarios is generally similar to the percent of particles entrained (Figure 42). Entrainment from the south Delta and central Delta sources is decreased by the optimized gate operations, while entrainment from the Upper Sacramento River region increases as a result of gate operations.

In addition to reduced entrainment due to less negative flows on Old River, resulting in reduced entrainment from western and central Delta sources, it is likely that the gate operations decrease entrainment by providing some recirculation of flow from Middle River to Old River. This circulation may cause increased residence/transit time of fish in the central and south Delta. Particles that are recirculated are less likely to be entrained by the end of the simulation (Figure 42). Furthermore if recirculated particles are entrained, they will be older, leading to a lower predicted entrainment after adjustment for natural mortality. Though not accounted for in the present analysis, the increased residence time also allows the fish to grow larger and potentially reach a size where active swimming behavior would reduce their likelihood of entrainment.

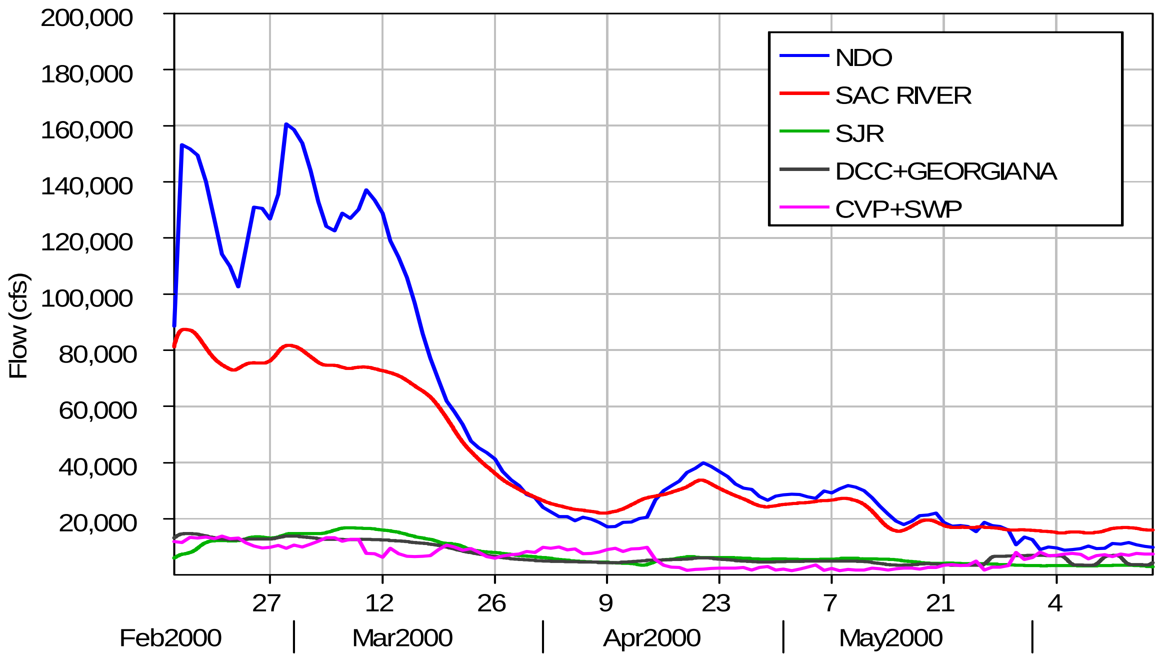


Figure 34 Net flows from the 2000 Historical simulation.

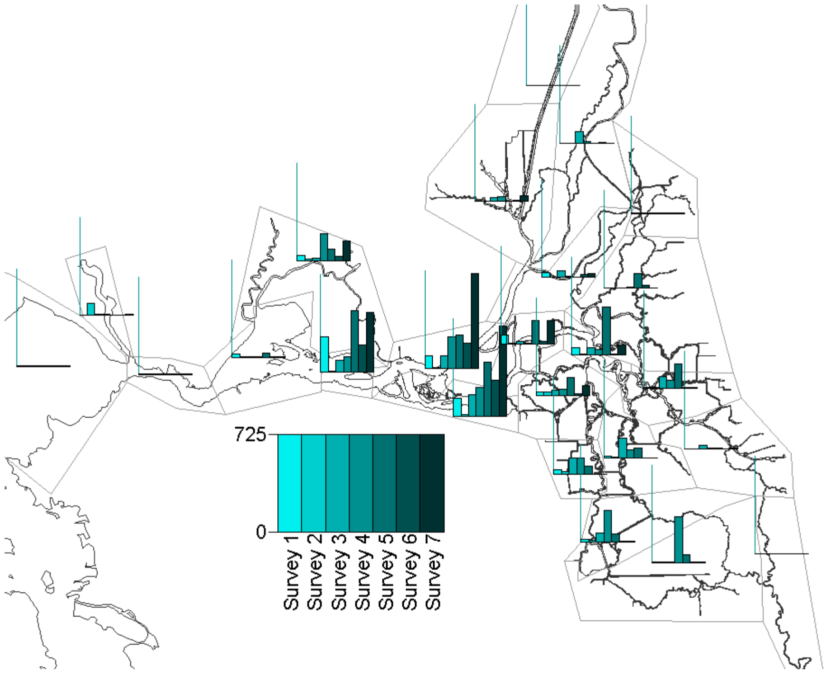


Figure 35 Regional Densities estimated from 20 mm Trawl Surveys, 2000.

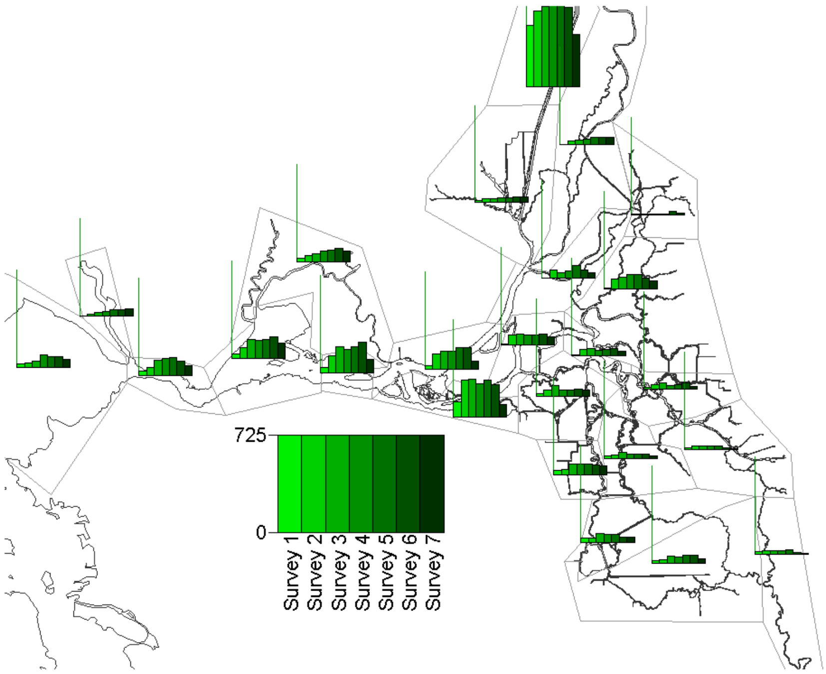


Figure 36 Regional Densities estimated by the Particle Model on survey dates, 2000.

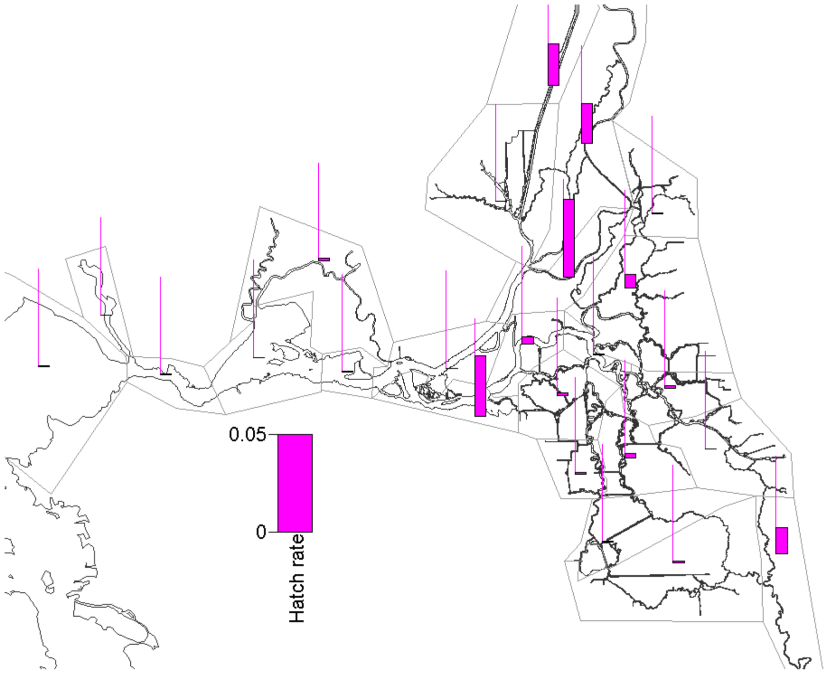


Figure 37 Tuned Regional Hatching Rates, 2000.

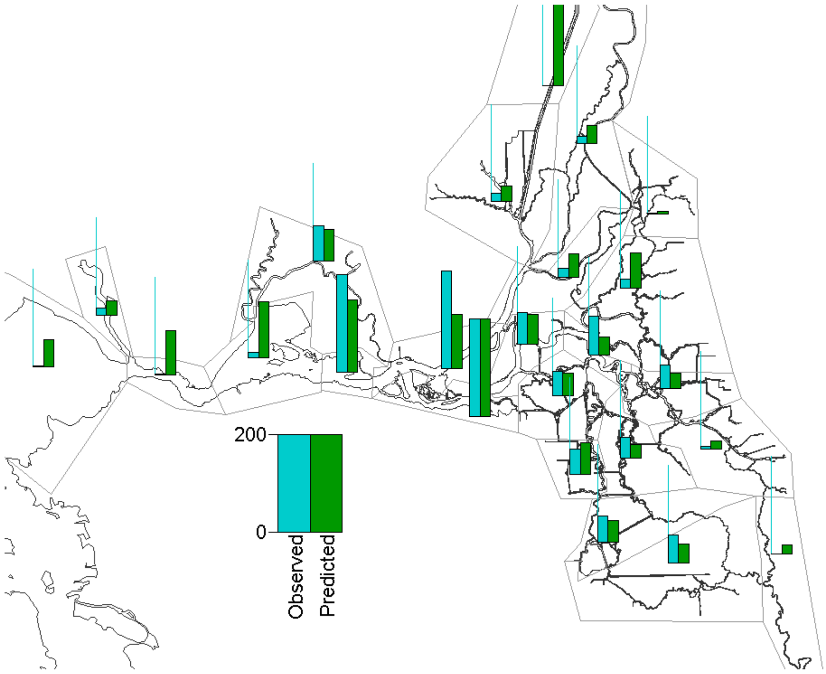


Figure 38 Comparison of Regional Densities estimated from 20 mm Trawl Surveys and Predicted by Particle Model averaged over all surveys, 2000.

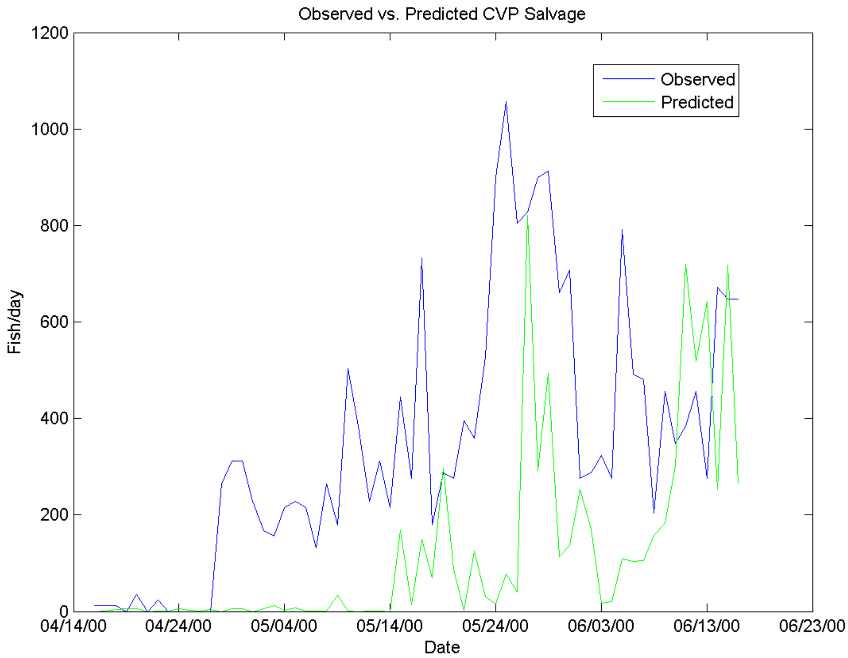


Figure 39 Time-series of Observed CVP Salvage and Salvage estimated from Particle Entrainment, 2000.

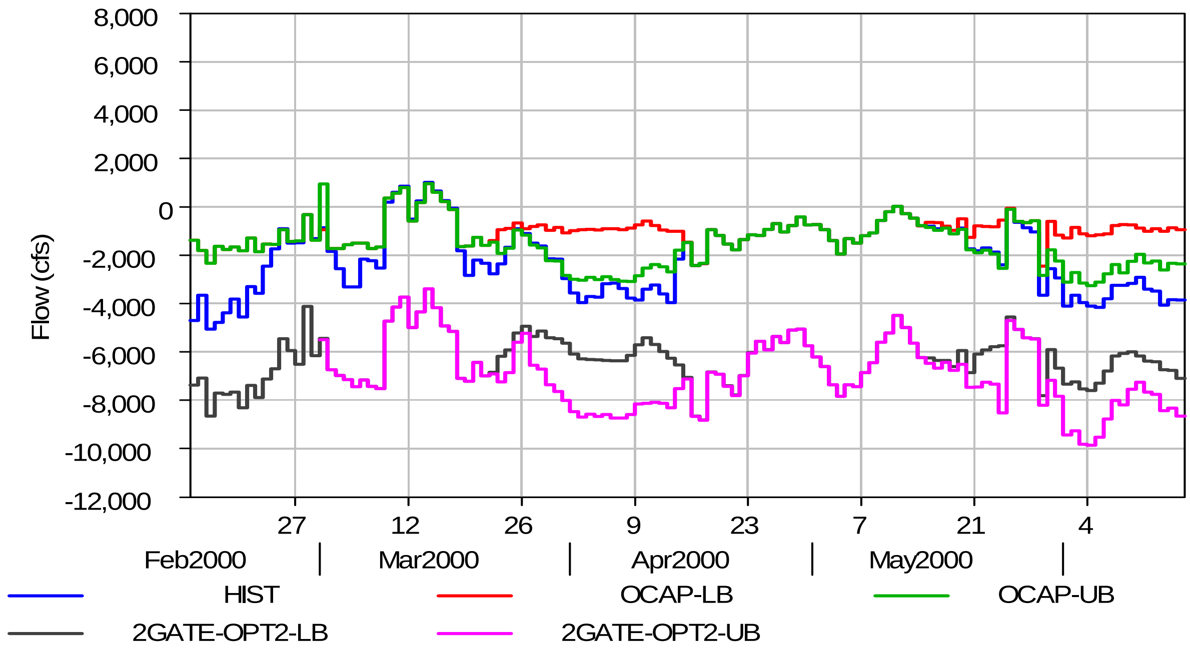


Figure 40 Daily average flows for February – June 2000 at RMID015.

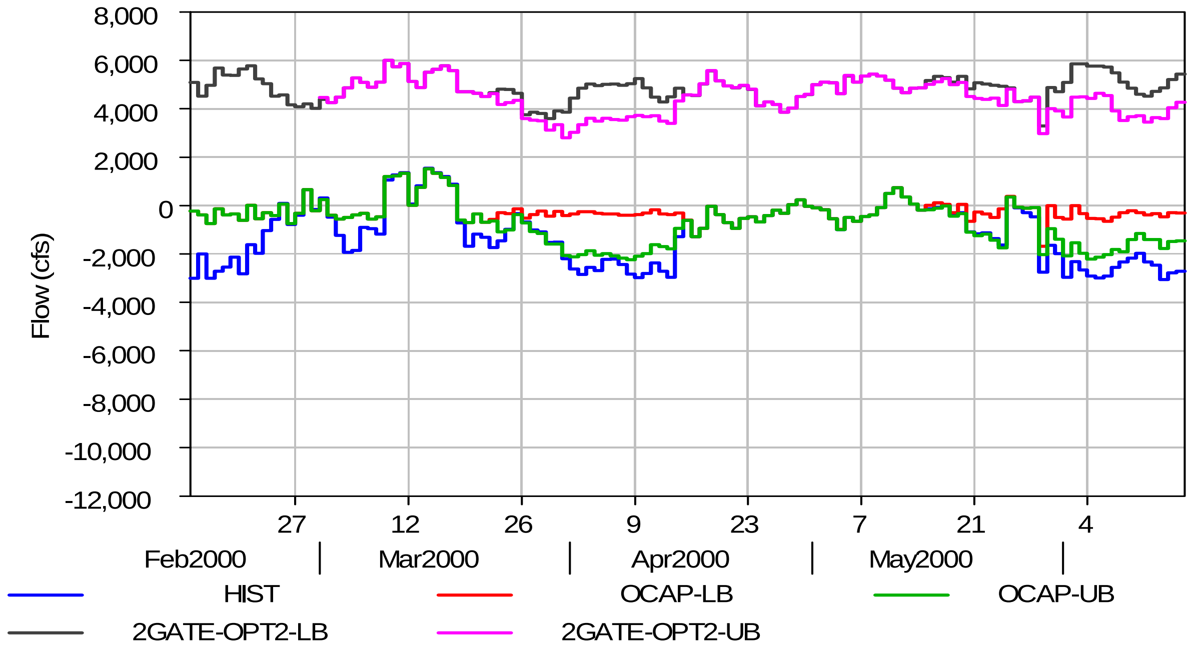


Figure 41 Daily average flows for February – June 2000 at ROLD024.

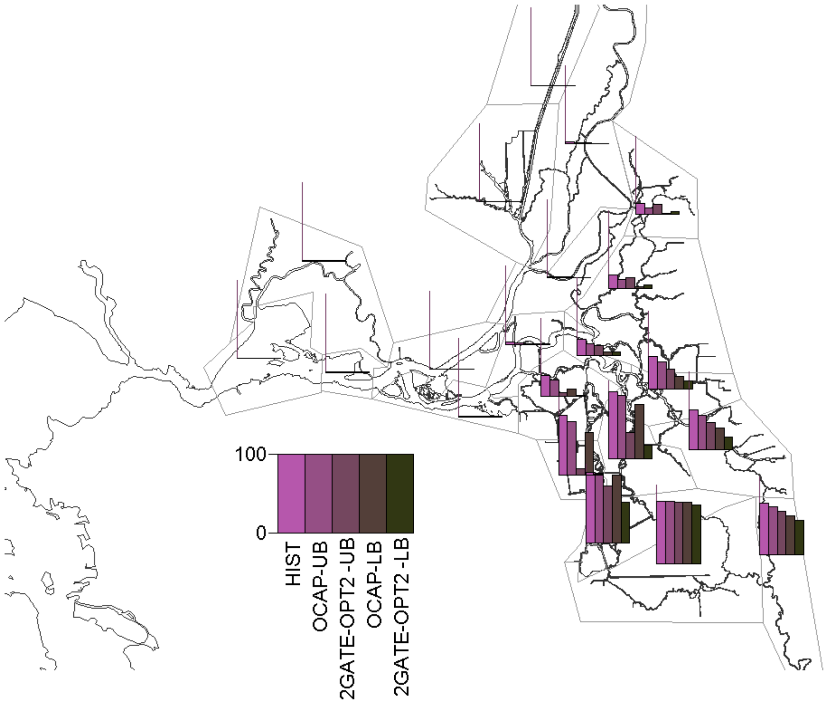


Figure 42 Percentage particles entrained at CVP+SWP from each region during the period February 15 - June 15, 2000.

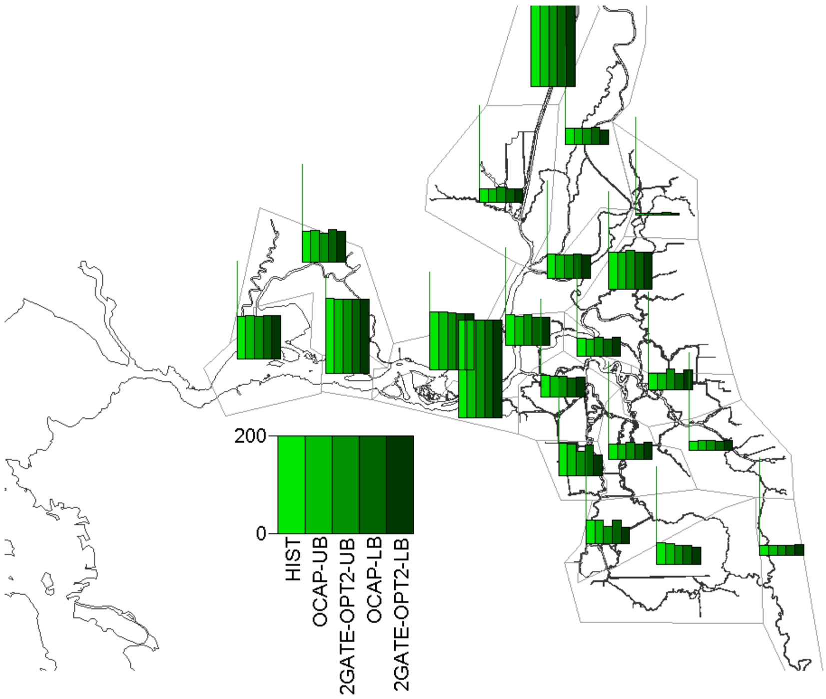


Figure 43 Regional Densities for the historical simulation and the scenarios averaged over the simulation period in 2000.

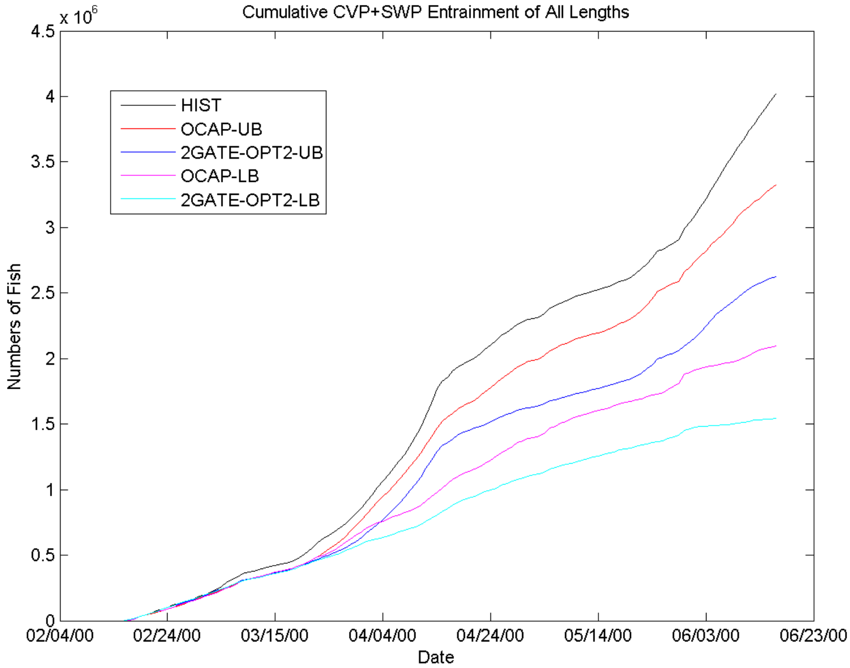


Figure 44 Cumulative Number of Fish of all lengths entrained at CVP+SWP for the historical simulation and the scenarios in 2000.

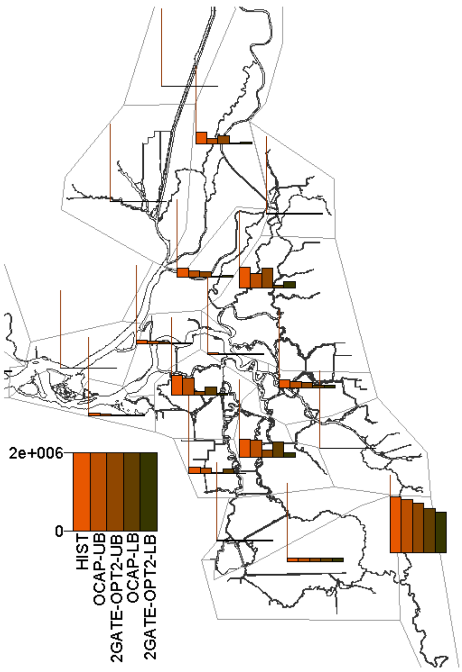


Figure 45 Cumulative Number of Fish of all lengths entrained at CVP+SWP from each region for the historical simulation and the scenarios in 2000.

Discussion of Results for 2003

The observed regional densities for surveys 1 through 7 in 2003, determined by spatial averaging of observations at 20mm survey stations, are shown in Figure 47. The observed densities vary strongly, both spatially and temporally, with many regions showing zero density due either to a lack of sampling (no stations sampled) or zero catch at all stations sampled. In the many regions in which no stations were sampled, the density is unknown and, therefore, the tuning approach does not attempt to match those regions.

The hatching rate distribution determined by the tuning approach to best match available observations is shown in Figure 49. This hatching rate distribution is strongly variable spatially with large hatching in the northern Delta. In years with larger observed delta smelt densities (e.g. 1999) the same tuning approach indicated substantial hatching in the western Delta and central Delta, which is largely absent in 2003. Therefore the predicted hatching distribution in 2003 is suspect. It seems likely that a more widely dispersed hatching distribution, less concentrated in the north Delta, actually occurred in 2003.

The observed and predicted regional densities averaged across surveys 1 through 7 are shown in Figure 50. This figure suggests that the average distribution through the simulation period is predicted quite well. In Figure 48, the predicted regional densities are shown for each region from survey 1 through 7. The predicted regional densities show a more persistent spatial and temporal pattern than the observed regional densities. In general, densities increase in most regions during the hatching period and then decrease due to mortality after hatching ends. An additional factor is Delta outflow and operations, which change the residence time of the particles/fish and can redistribute them through the Delta.

The observed and predicted daily CVP salvage at the Tracy Fish Facility from April 15, 2003 to June 15, 2003 is shown in Figure 51. The predicted magnitude of entrainment is similar to the observations while the daily variability is different. Some “noise” may be present in the predicted salvage due to the finite number of particles used in the simulation resulting in a relatively small number of particles with age corresponding to length greater than 20mm that arrive at the Tracy Fish Facility each day.

Both the changes in export flows and gate operations significantly influence predicted delta smelt distribution and entrainment in 2003. In all scenarios, high predicted fish densities are present in the Sacramento Ship Channel region due to high hatching rates estimated by the tuning method and long residence times in this region. The largest estimated regional hatching rates are the Sacramento Ship Channel region hatching rate of 0.04 fish m^{-2} day^{-1} and the Mid Sacramento region hatching rate of 0.034 fish m^{-2} day^{-1}. The results for all scenarios are strongly influenced by this hatching distribution because the source of most fish is the north Delta.

In 2003 and other simulation periods, the results can be understood largely in terms of effects on distinct flow corridors. One flow corridor of interest is from the north Delta through the Delta Cross

Channel and Georgiana Slough, then through the San Joaquin River, Old River and, eventually, Middle River, or the "Middle River corridor." While the reduced flows in OCAP reduce the flows through this corridor, the gate operations increase flows along this corridor by making Middle River flows more negative and Old River flows less negative, as shown in Figure 52 and Figure 53. However, in 2003 a complicating factor is substantial hatching in the Disappointment region. The gate operations decrease predicted density in the Disappointment region, perhaps by circulating these fish into Middle River more rapidly, thereby decreasing residence time in the Disappointment region. Overall, the predicted densities in the Middle region are decreased by the OCAP limitations but show little effect from the gate operations.

Both the OCAP flow reductions and the gate operations make flows on the Old River less negative, as shown in Figure 53. Therefore fewer particles/fish are drawn from Franks Tract and the San Joaquin near Old River under these scenarios than the historical scenarios. The Old River region shows decreases in the predicted fish density as a result of OCAP flow limitations. The predicted densities are decreased further as a result of the optimized gate operations for 2GATE-OPT2-UB but show a slight increase for 2GATE-OPT2-LB compared with OCAP-LB. The increase may result from an increase in particles transported in to Old River from Middle River. In 2003 the predicted density for the 2GATE-OPT2-LB scenario in the source regions for Old River were comparable or larger than the predicted density in central Delta regions that are the source regions for Middle River under the OCAP-LB scenario. Both Middle River and Old River serve as transport corridors to the "far" south Delta, represented by the Victoria region and the Grant Line and Old region. The gate operations make the Middle River corridor the dominant corridor of transport to the "far" south Delta. The net effect of the gate operations in the Victoria region and the Grant Line and Old region is decreased density, with the exception of a slight increase in density in the Grant Line and Old region for the 2GATE-OPT2-LB scenario relative to the OCAP-LB scenario.

The decreased predicted density in these south Delta regions results in decreased predicted entrainment as a result of OCAP flow limitations. The gate operations have a smaller influence on the total entrainment in 2003 with minimal influence on the total entrainment. The number of particles from each source region that are entrained is shown in Figure 54. In regions with non-zero hatching the variability of predicted fish entrainment among scenarios is generally similar to the percent of particles entrained (Figure 54). Entrainment from the south Delta and central Delta sources is decreased by the optimized gate operations, while entrainment from the Upper Sacramento River region increases as a result of gate operations.

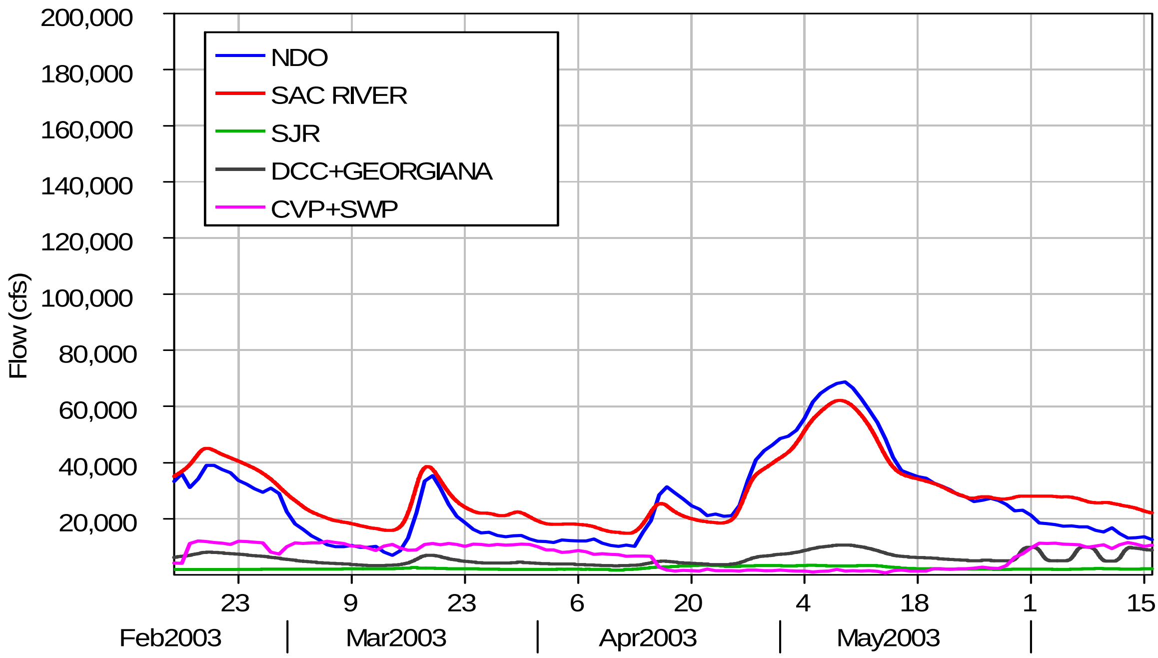


Figure 46 Net flows from the 2003 Historical simulation.

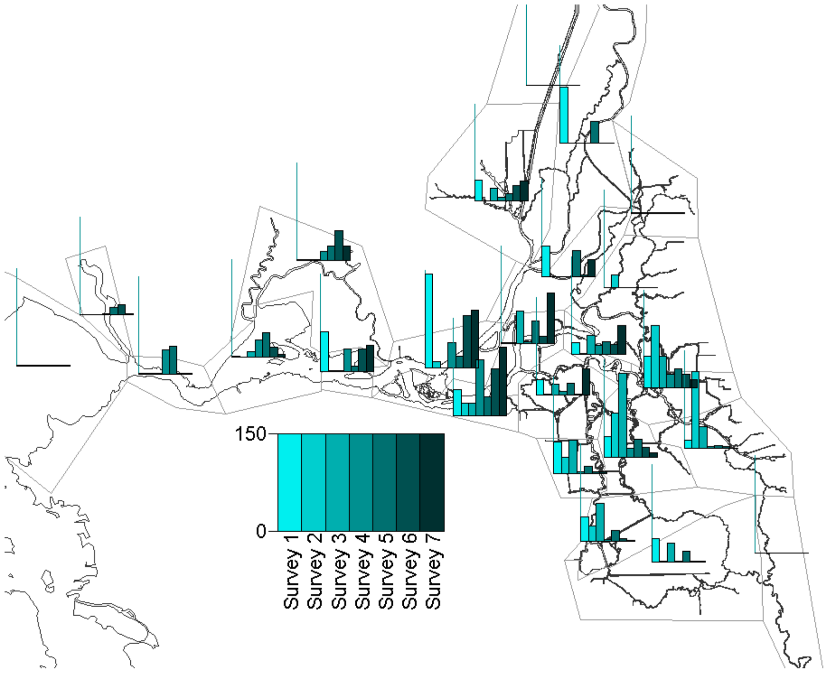


Figure 47 Regional Densities estimated from 20 mm Trawl Surveys, 2003.

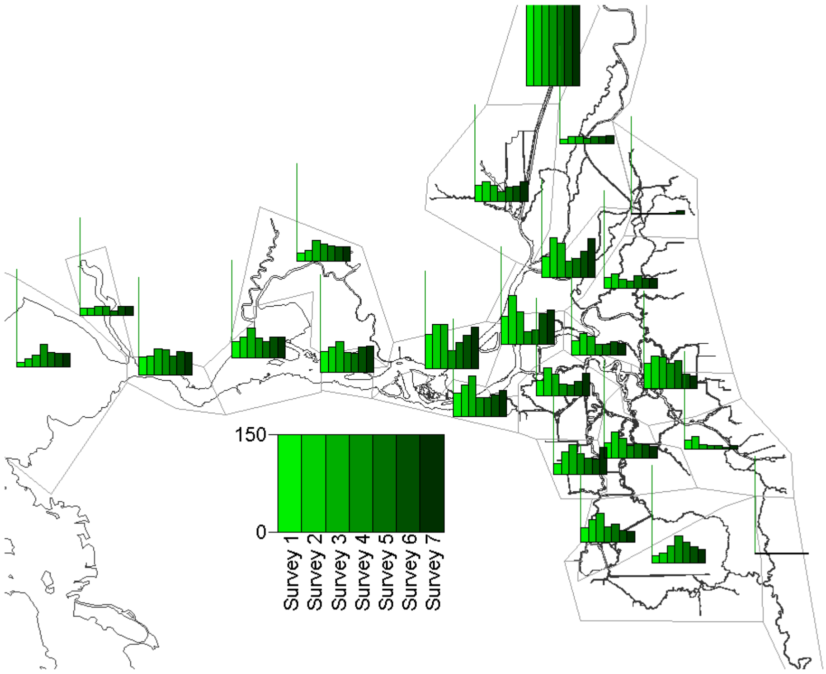


Figure 48 Regional Densities estimated by the Particle Model on survey dates, 2003.

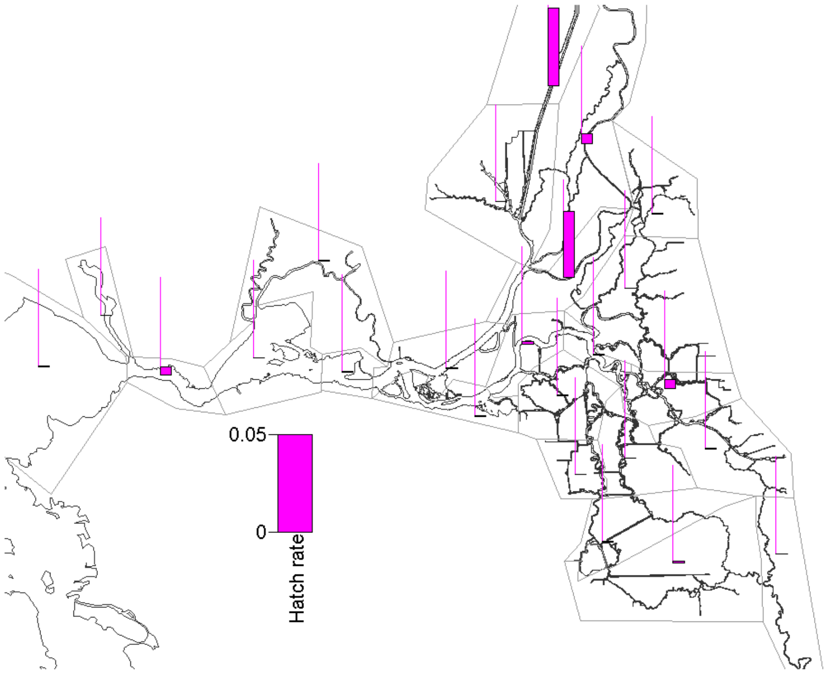


Figure 49 Tuned Regional Hatching Rates, 2003.

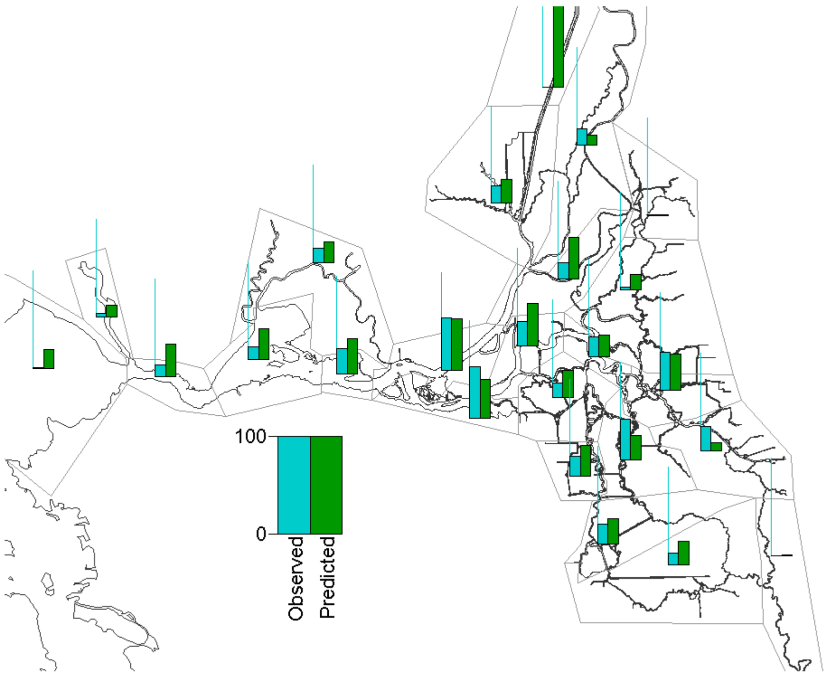


Figure 50 Comparison of Regional Densities estimated from 20 mm Trawl Surveys and Predicted by Particle Model averaged over all surveys, 2003.

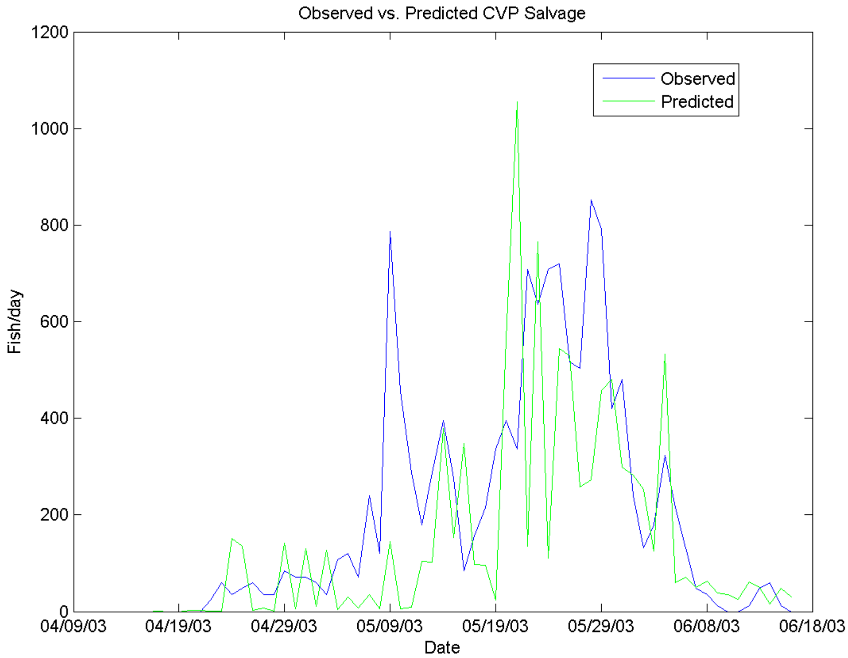


Figure 51 Time-series of Observed CVP Salvage and Salvage estimated from Particle Entrainment, 2003.

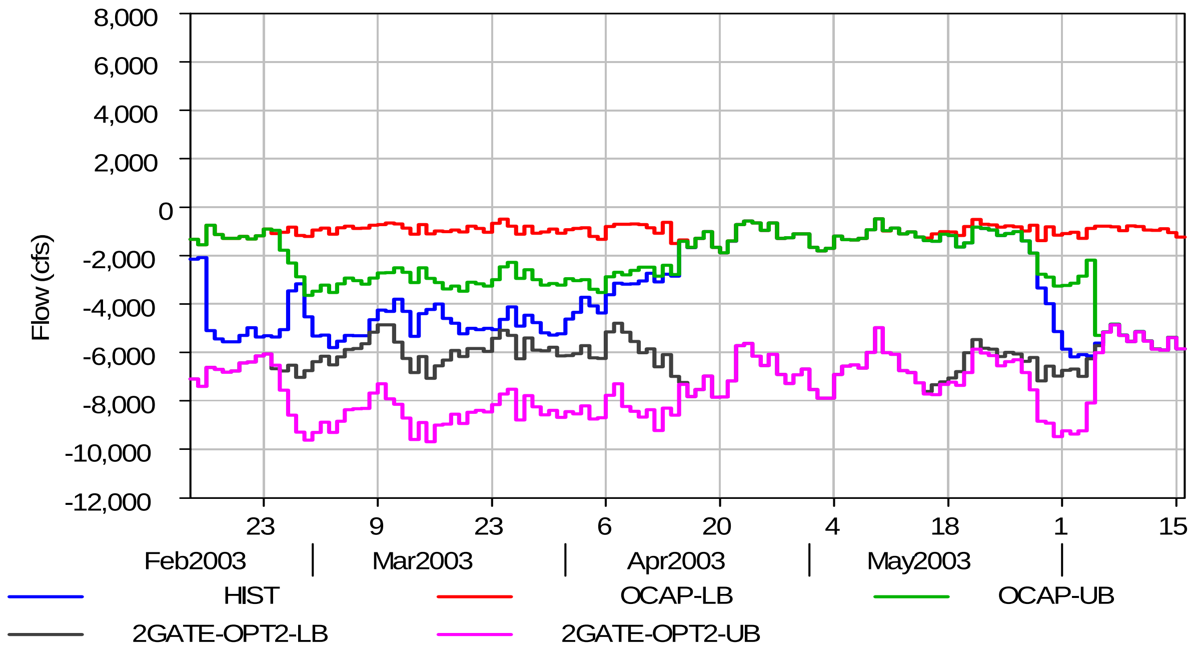


Figure 52 Daily average flows for February – June 2003 at RMID015.

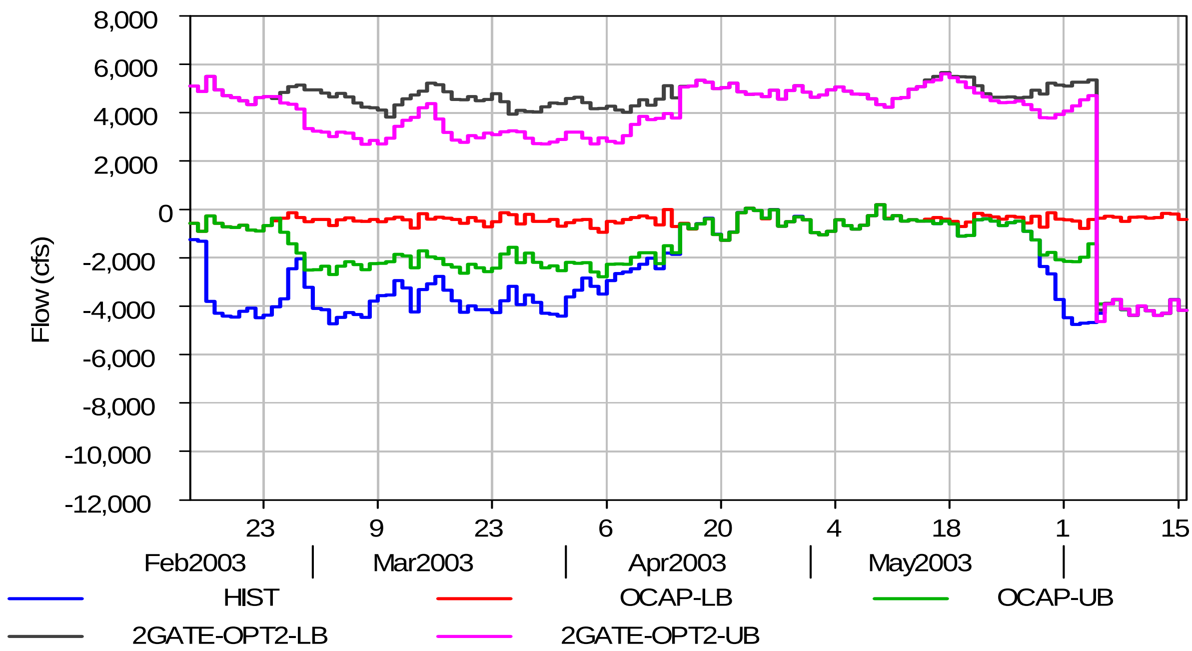


Figure 53 Daily average flows for February – June 2003 at ROLD024.

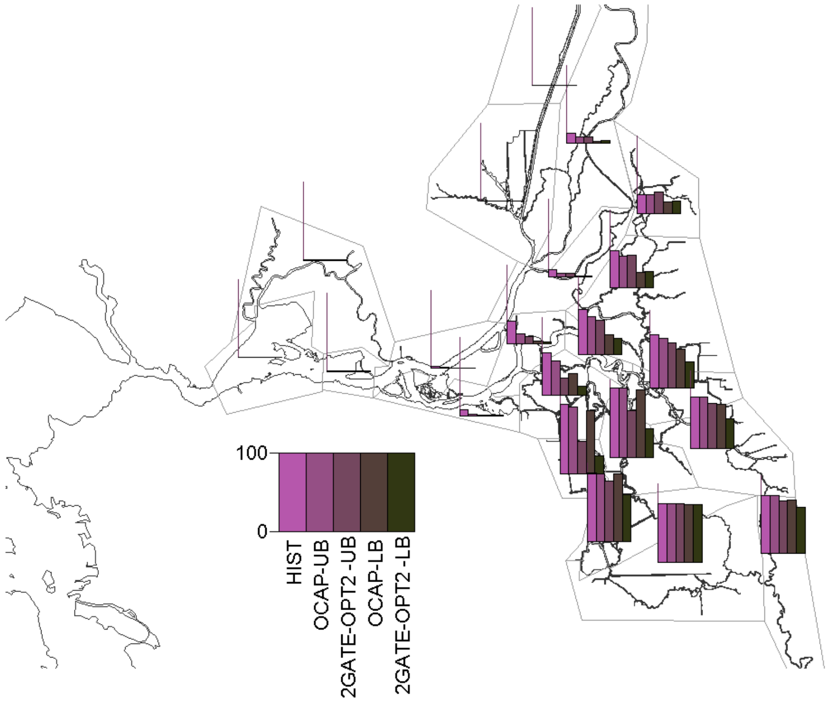


Figure 54 Percentage particles entrained at CVP+SWP from each region during the period February 15 - June 15, 2003.

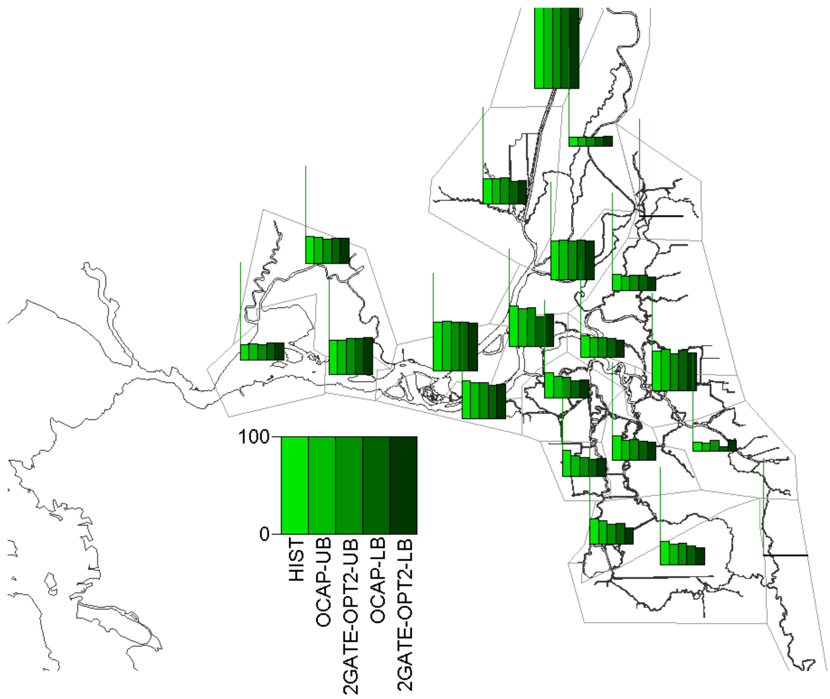


Figure 55 Regional Densities for the historical simulation and the scenarios averaged over the simulation period in 2003.

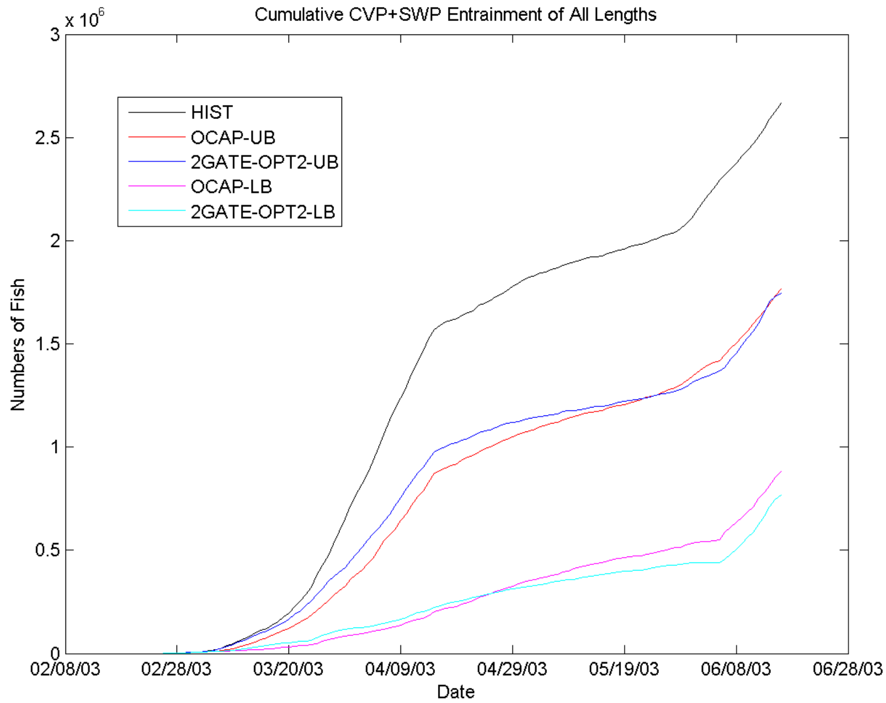


Figure 56 Cumulative Number of Fish of all lengths entrained at CVP+SWP for the historical simulation and the scenarios in 2003.

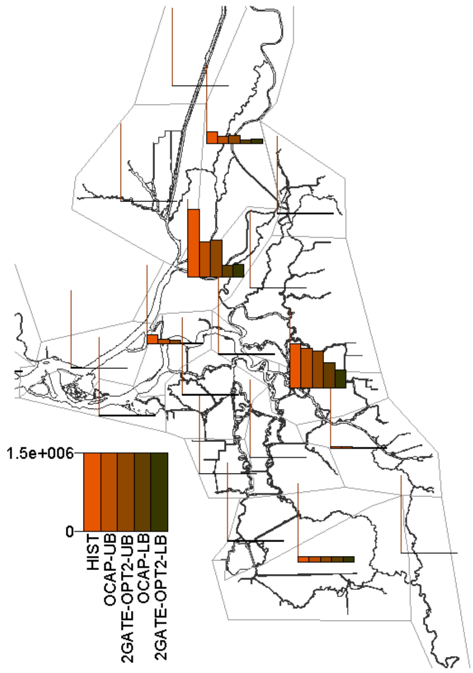


Figure 57 Cumulative Number of Fish of all lengths entrained at CVP+SWP from each region for the historical simulation and the scenarios in 2003.

Discussion of Results for 2004

The observed regional densities for surveys 1 through 8 in 2004, determined by spatial averaging of observations at 20mm survey stations, are shown in Figure 59. The observed densities vary strongly, both spatially and temporally, with many regions showing zero density due either to a lack of sampling (no stations sampled) or zero catch at all stations sampled and a large "spike" in density for survey 4 in the San Joaquin at False River region. In the many regions in which no stations were sampled, the density is unknown and, therefore, the tuning approach does not attempt to match those regions.

The hatching rate distribution determined by the tuning approach to best match available observations is shown in Figure 61. This hatching rate distribution is strongly variable spatially with large hatching in the northern Delta.

The observed and predicted regional densities averaged across surveys 1 through 8 are shown in Figure 62. This figure suggests that the average distribution through the simulation period is predicted quite well though density is generally underestimated in the central Delta. In Figure 60, the predicted regional densities are shown for each region from survey 1 through 8. The predicted regional densities show a more persistent spatial and temporal pattern than the observed regional densities. In general, densities increase in most regions during the hatching period and then decrease due to mortality after hatching ends. An additional factor is Delta outflow and operations which change the residence time of the particles/fish and can redistribute them through the Delta.

The observed and predicted daily CVP salvage at the Tracy Fish Facility from April 15, 2004 to June 15, 2004 is shown in Figure 63. The overall predicted magnitude of entrainment is similar to the observations but the temporal trends are different. The salvage is typically underestimated through mid May and then overestimated in most of the remaining period. The poor comparison to observed salvage in June may be partially a result of using passive particles to represent delta smelt. It is likely that most of the delta smelt present in the Delta in June are large enough to exhibit some behavior.

Both the changes in export flows and gate operations significantly influence predicted delta smelt distribution and entrainment in 2004. In all scenarios, high predicted fish densities are present in the Sacramento Ship Channel region and the Cache Slough and Liberty Island region due to high hatching rates estimated by the tuning method and long residence times in these regions. The largest estimated regional hatching rate is the Upper Sacramento region hatching rate of 0.02 fish m^{-2} day^{-1}, though the predicted densities are moderate due to limited residence time in this region. The results for all scenarios are strongly influenced by this hatching distribution because the source of most fish is the north Delta.

In 2004 and other simulation periods, the results can be understood largely in terms of effects on distinct flow corridors. One flow corridor of interest is from the north Delta through the Delta Cross

Channel and Georgiana Slough, then through the San Joaquin River, Old River and, eventually, Middle River, or the "Middle River corridor." While the reduced flows in OCAP reduce the flows through this corridor, the gate operations increase flows along this corridor by making Middle River flows more negative and Old River flows less negative (see Figure 64 and Figure 65). Therefore, the densities are typically reduced along the Middle River corridor as a result of OCAP, relative to the historical scenario, as fewer particles/fish are drawn from the source region in the northern Delta. In contrast, the predicted densities are generally increased along this corridor by the gate operations which make flows more negative, and therefore pull more fish from the source region.

In contrast, both the OCAP flow reductions and the gate operations make flows on the Old River less negative (Figure 65). Therefore fewer particles/fish are drawn from Franks Tract and the San Joaquin near Old River under these scenarios than the historical scenarios. The Old River region shows decreases in the predicted fish density as a result of OCAP flow limitations. The predicted densities are decreased further as a result of the optimized gate operations. Both Middle River, where density is increased as a result of gate operations, and Old River, where density is decreased as a result of gate operations, serve as transport corridors to the "far" south Delta, represented by the Victoria region and the Grant Line and Old region. The gate operations make the Middle River corridor the dominant corridor of transport to the "far" south Delta. The net effect of the gate operations in the Victoria region and the Grant Line and Old region is decreased density.

The decreased predicted density in these south Delta regions results in decreased predicted entrainment as a result of OCAP flow limitations. The gate operations have a smaller influence on the total entrainment in 2004, slightly decreasing the total entrainment in this simulation period. The number of particles from each source region that are entrained is shown in Figure 66. In regions with non-zero hatching the variability of predicted fish entrainment among scenarios is generally similar to the percent of particles entrained (Figure 66). Entrainment from the south Delta and central Delta sources is decreased by the optimized gate operations, while entrainment from the Upper Sacramento River region increases as a result of gate operations. Considering a broad area of the central and southern Delta, the gate operations provide significant reduction in the "unscaled" entrainment over the course of the simulation. Time series of percent cumulative entrainment from the "unscaled" particle tracking results are shown in Figure 70, based on a volume weighted average from the individual regional entrainment for "SJR near confluence," "SJR near False River," "SJR at Old River," "Franks Tract," "South Fork Mokelumne," "Disappointment," "Middle," and "Old" . The gate operation reduces cumulative entrainment relative to the corresponding OCAP simulations by approximately 50%.

In addition to reduced entrainment due to less negative flows on Old River, resulting in reducing entrainment from western and central Delta sources, it is likely that the gate operations decrease entrainment by providing some recirculation of flow from Middle River to Old River. This circulation may cause increased residence/transit time of fish in the central and south Delta. Particles that are recirculated are less likely to be entrained by the end of the simulation Figure 66. Furthermore if recirculated particles are entrained, they will be older, leading to a lower predicted entrainment after adjustment for natural mortality. Though not accounted for in the present analysis, the increased residence time also allows the fish to grow larger and potentially reach a size where active swimming behavior would reduce their likelihood of entrainment.

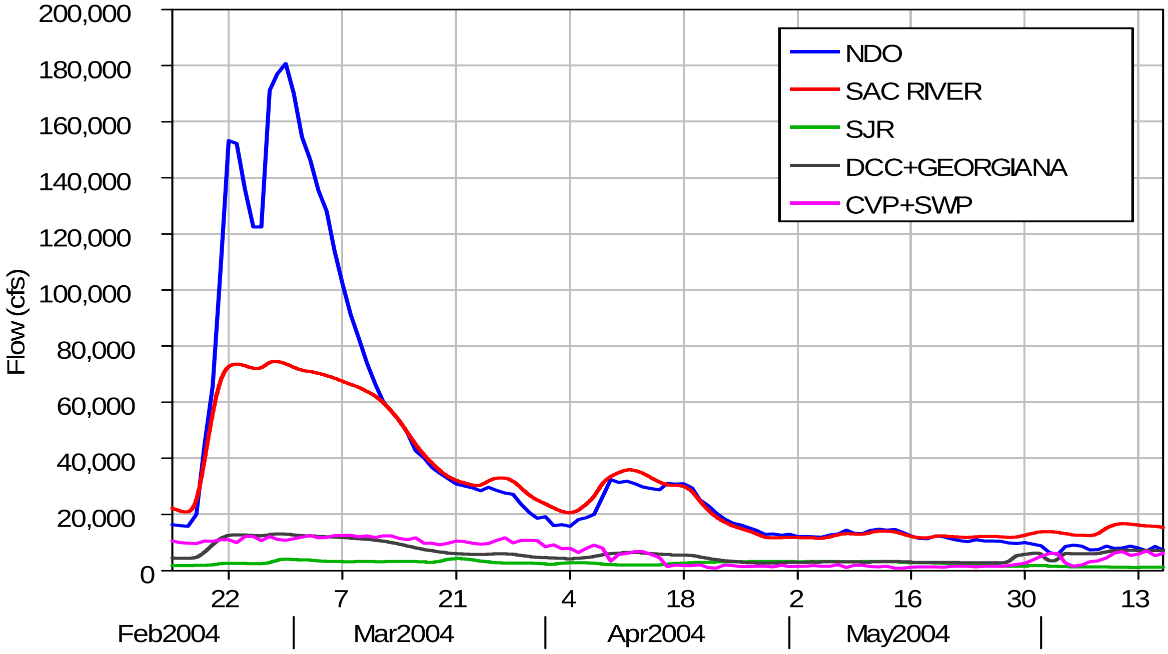


Figure 58 Net flows from the 2004 Historical simulation.

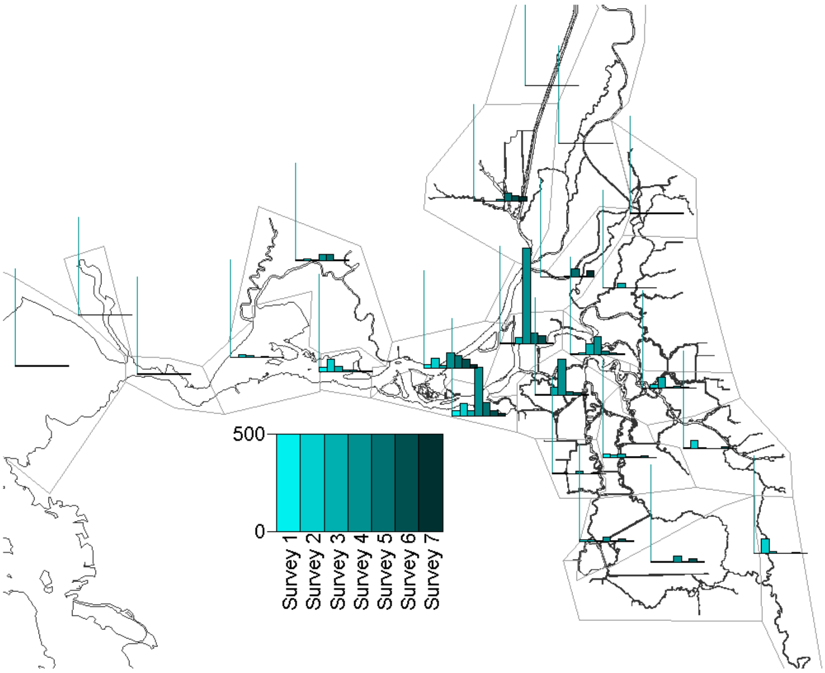


Figure 59 Regional Densities estimated from 20 mm Trawl Surveys, 2004.

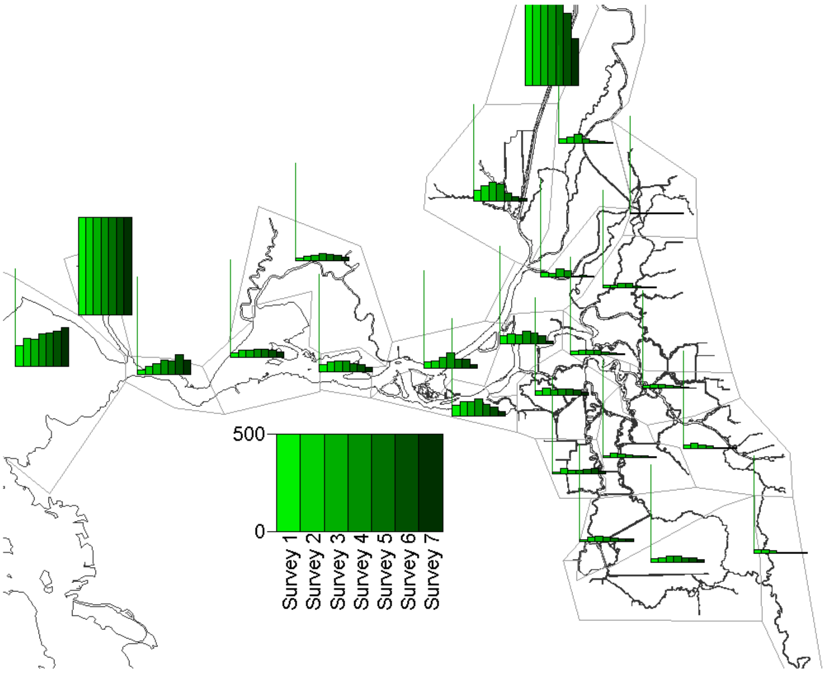


Figure 60 Regional Densities estimated by the Particle Model on survey dates, 2004.

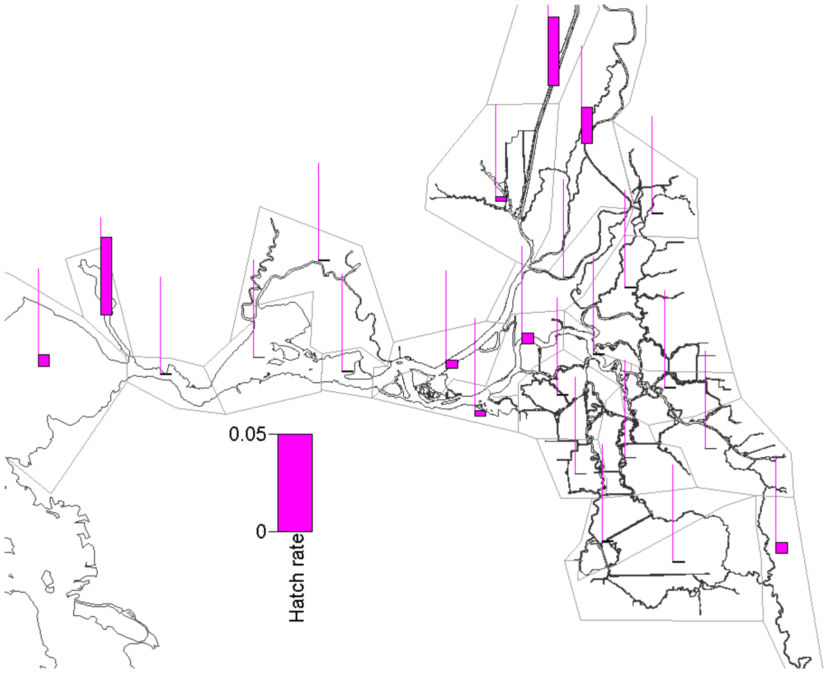


Figure 61 Tuned Regional Hatching Rates, 2004.

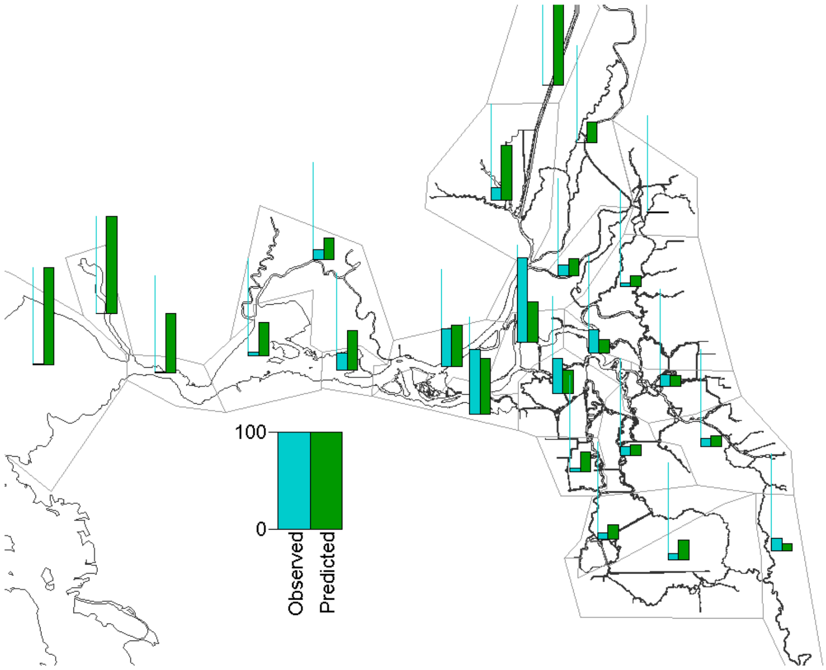


Figure 62 Comparison of Regional Densities estimated from 20 mm Trawl Surveys and Predicted by Particle Model averaged over all surveys, 2004.

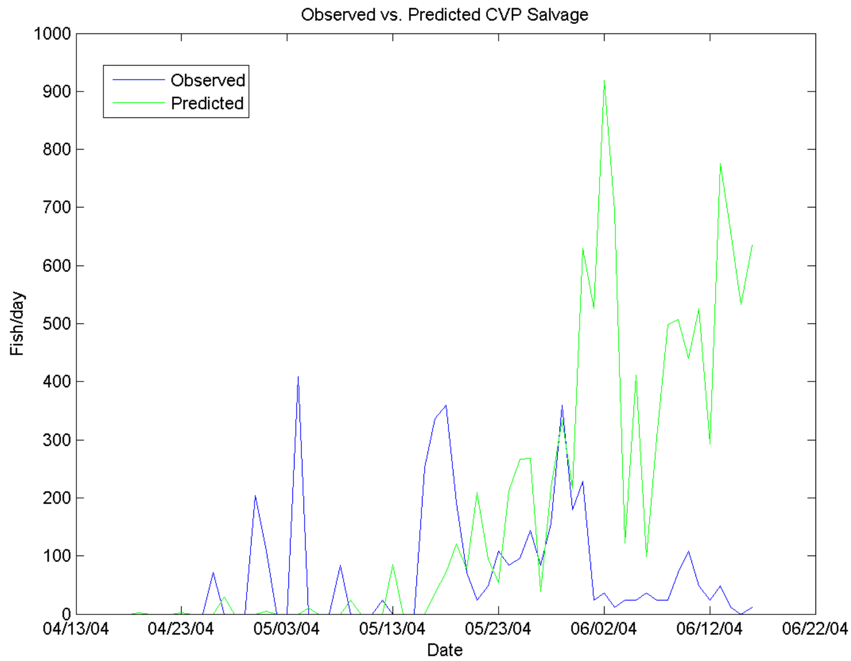


Figure 63 Time-series of Delta-wide Population estimated from 20 mm Trawl Surveys and from Particle Model, 2004.

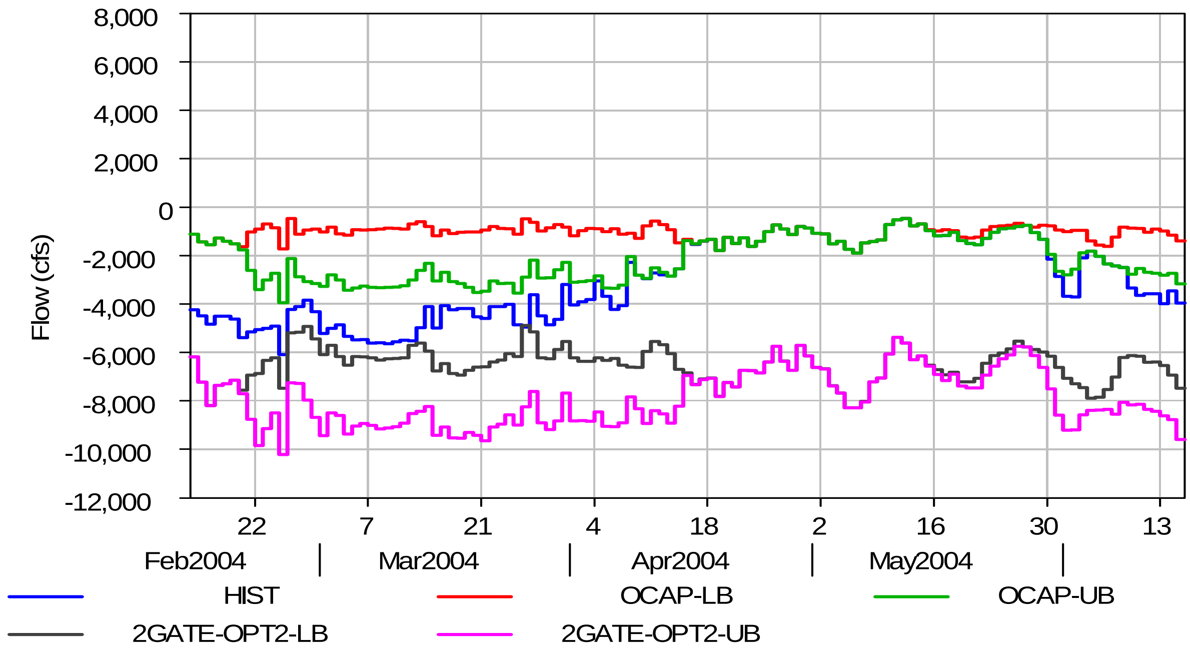


Figure 64 Daily average flows for February – June 2004 at RMID015.

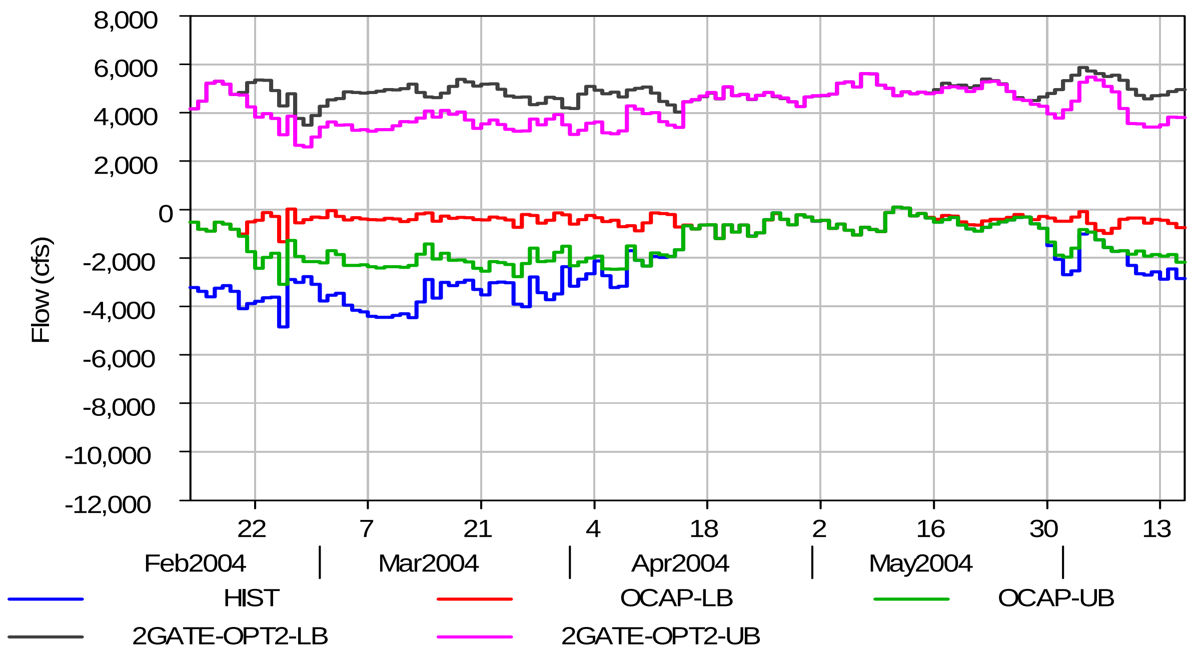


Figure 65 Daily average flows for February – June 2004 at ROLD024.

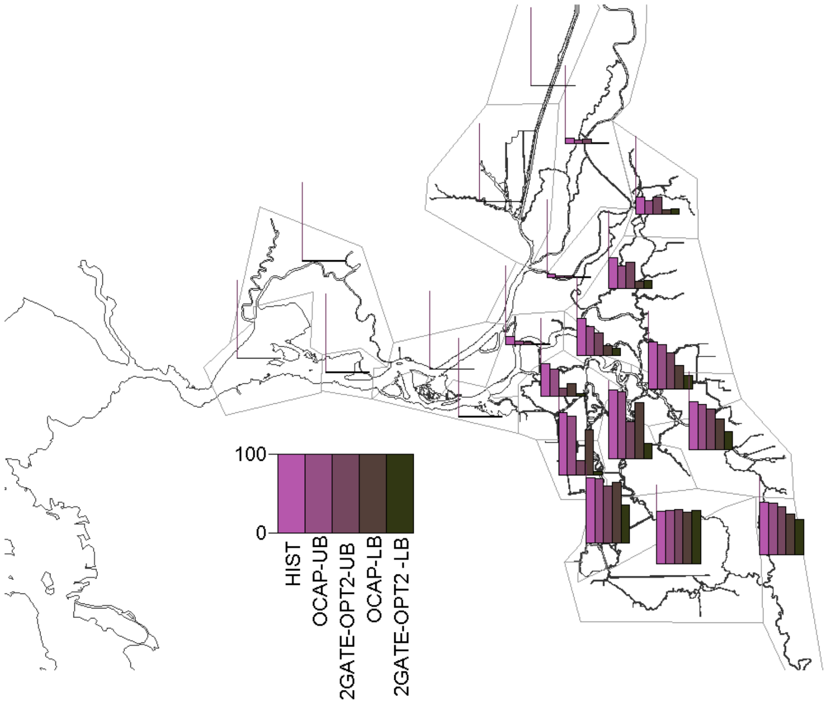


Figure 66 Percentage particles entrained at CVP+SWP from each region during the period February 15 - June 15, 2004.

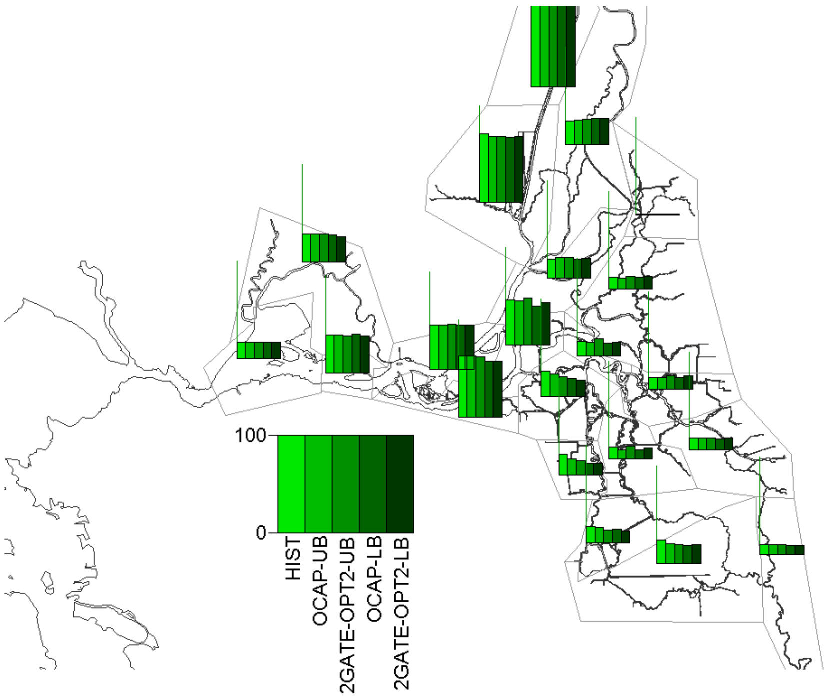


Figure 67 Regional Densities for the historical simulation and the scenarios averaged over the simulation period in 2004.

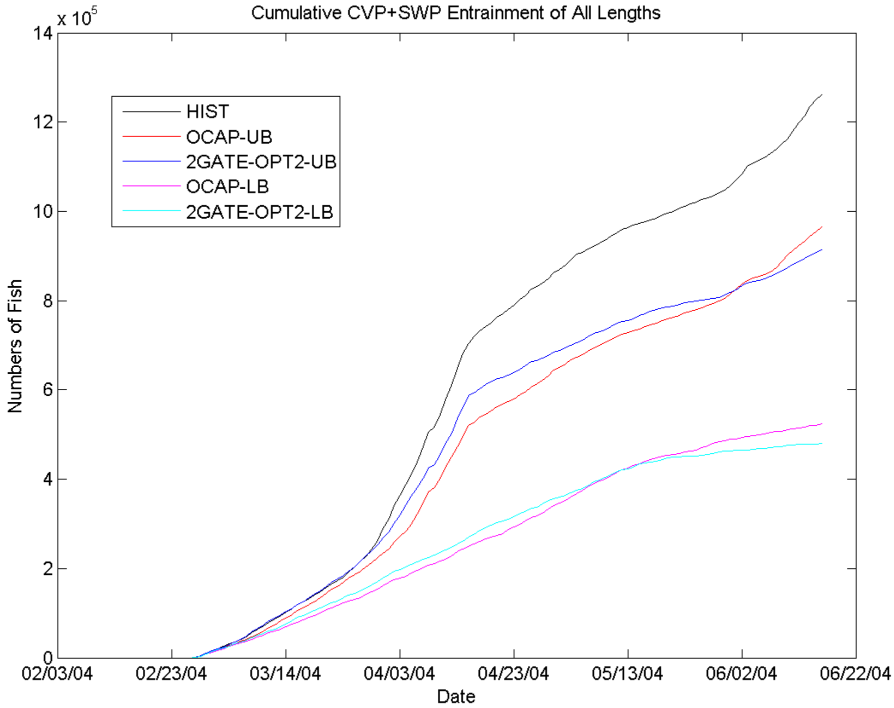


Figure 68 Cumulative Number of Fish of all lengths entrained at CVP+SWP for the historical simulation and the scenarios in 2004.

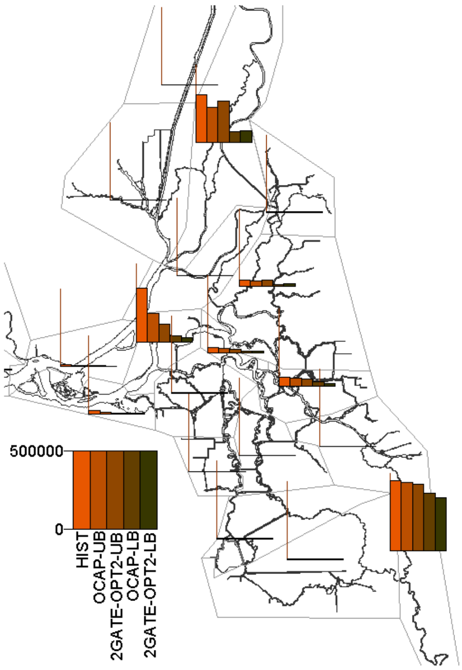


Figure 69 Cumulative Number of Fish of all lengths entrained at CVP+SWP from each region for the historical simulation and the scenarios in 2004.

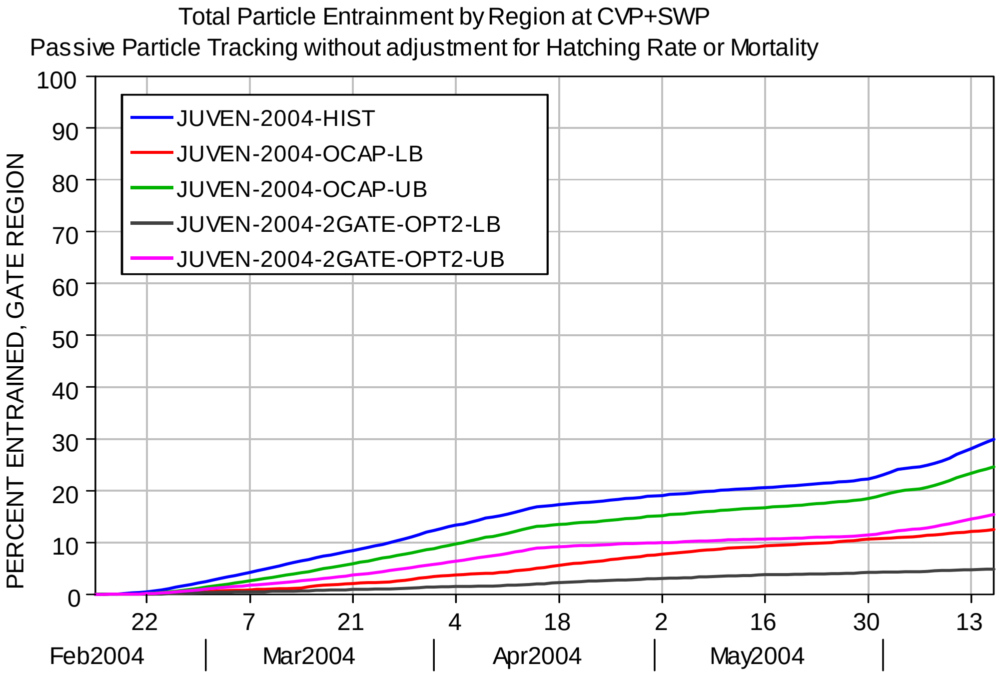


Figure 70 Percent particles entrained at the CVP+SWP originating from the region of influence of the gates, including "SJR near confluence," "SJR near False River," "SJR at Old River," "Franks Tract," "South Fork Mokelumne," "Disappointment," "Middle," and "Old" regions.

References

Bennet, W.A., 2004. Critical Assessment of the Delta Smelt Population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science, Vol. 3, Issue 2 (September), Article 1.

Denton, R.A., 1993. Accounting for Antecedent Conditions in Seawater Intrusion Modeling – Applications for the San Francisco Bay-Delta. Hydraulic Engineering 93, Vol1 pp. 448-453. Proceedings of the ASCE National Conference on Hydraulic Engineering, San Francisco.

DWR, 2005. Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh, 26th Annual Progress Report, October 2005.

DWR, 1995. "Estimation of Delta Island Diversions and Return Flows", February 1995.

Kimmerer, Wim J., 2008. Losses of Sacramento River Chinook Salmon and Delta Smelt *(Hypomesus transpacificus)* to Entrainment in Water Diversions in the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science. Vol. 6, Issue 2 (June), Article 2.

Kimmerer, W.J., and Nobriga, M.L., 2008. Investigating particle transport and fate in the Sacramento-San Joaquin Delta using a particle tracking model. San Francisco Estuary and Watershed Science, 6(1), Article 4.

King, I. P., 1995. "RMA11 – A Two-Dimensional Finite Element Quality Model", Resource Management Associates.

King, I. P., 1986 . "Finite Element Model for Two-Dimensional Depth Averaged Flow, RMA2V, Version 3.3", Resource Management Associates.

MacWilliams, M.L., and E.S. Gross, 2008. San Francisco Bay-Delta UnTRIM Model Calibration Report, POD 3-D Particle Tracking Modeling Study, prepared for CA Department of Water Resources, December 2008.

Miller W.J., 2005. Estimating the population of delta smelt using the Spring Kodiak trawl data, November, 2005, paper for the
December 2005 EWA Expert Panel meeting.

Price, K. and Storn, R., 1997. Differential Evolution: Numerical Optimization Made Easy. Dr. Dobb's Journal, April 97, pp. 18 - 24.

RMA, 2008. "RMATRK: Model Formulation and Testing".

RMA, 2005. "Flooded Islands Feasibility Study: RMA Delta Model Calibration Report", June 2005.

RMA, 2000. "Mathematical Modeling of Hydrodynamic and Water Quality Impacts of Suisun Marsh Levee Breaches", December 2000.