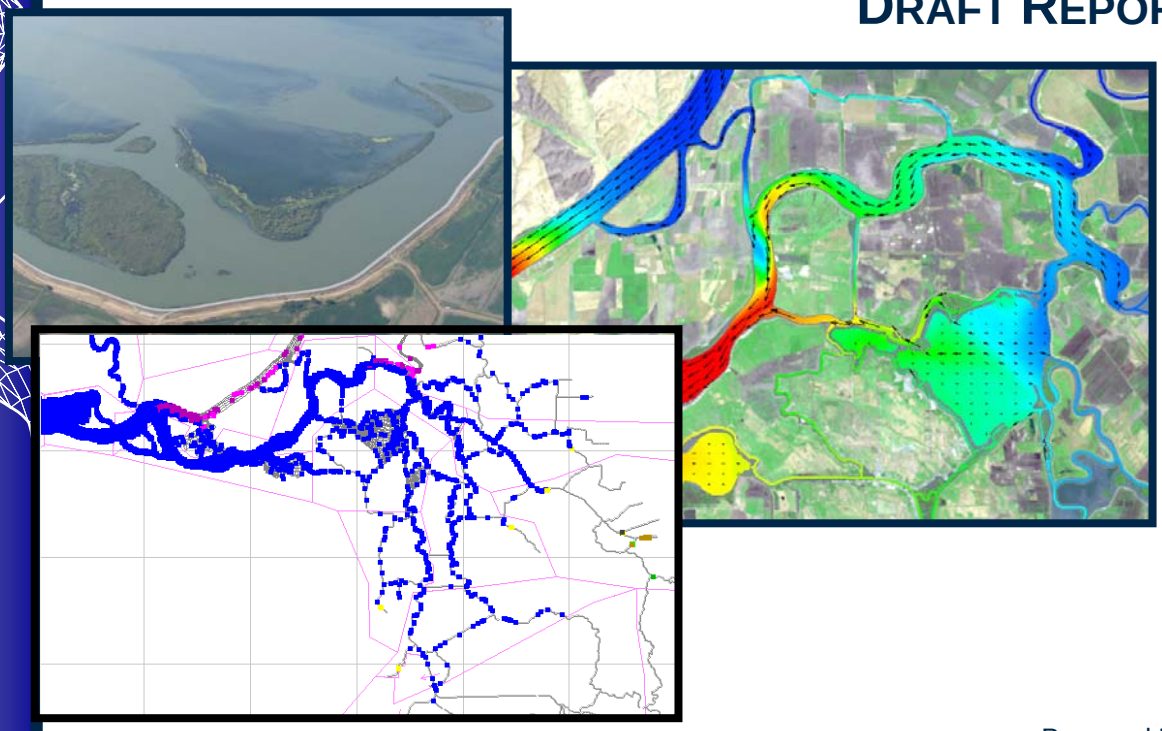
APPENDIX B

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

PARTICLE TRACKING AND ANALYSIS OF ADULT AND LARVAL/JUVENILE DELTA SMELT FOR 2-GATES DEMONSTRATION PROJECT

DRAFT REPORT



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Introduction

This report describes the numerical modeling analysis of potential entrainment of adult, juvenile, and larval delta smelt in support of the 2-Gates Demonstration Project. The objective of the modeling analysis is to examine the incremental benefit of operable barriers in Old River and Connection Slough relative to conditions under 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 of adult delta smelt occurs during the period when the fish choose to move upstream for spawning. Periods of peak entrainment are correlated with high turbidity in the neighborhood of the exports resulting from storm flows. 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 involves minimizing advective and dispersive transport from regions of the Delta where fish densities are highest.

Both the adult and larval/juvenile particle tracking analyses 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.

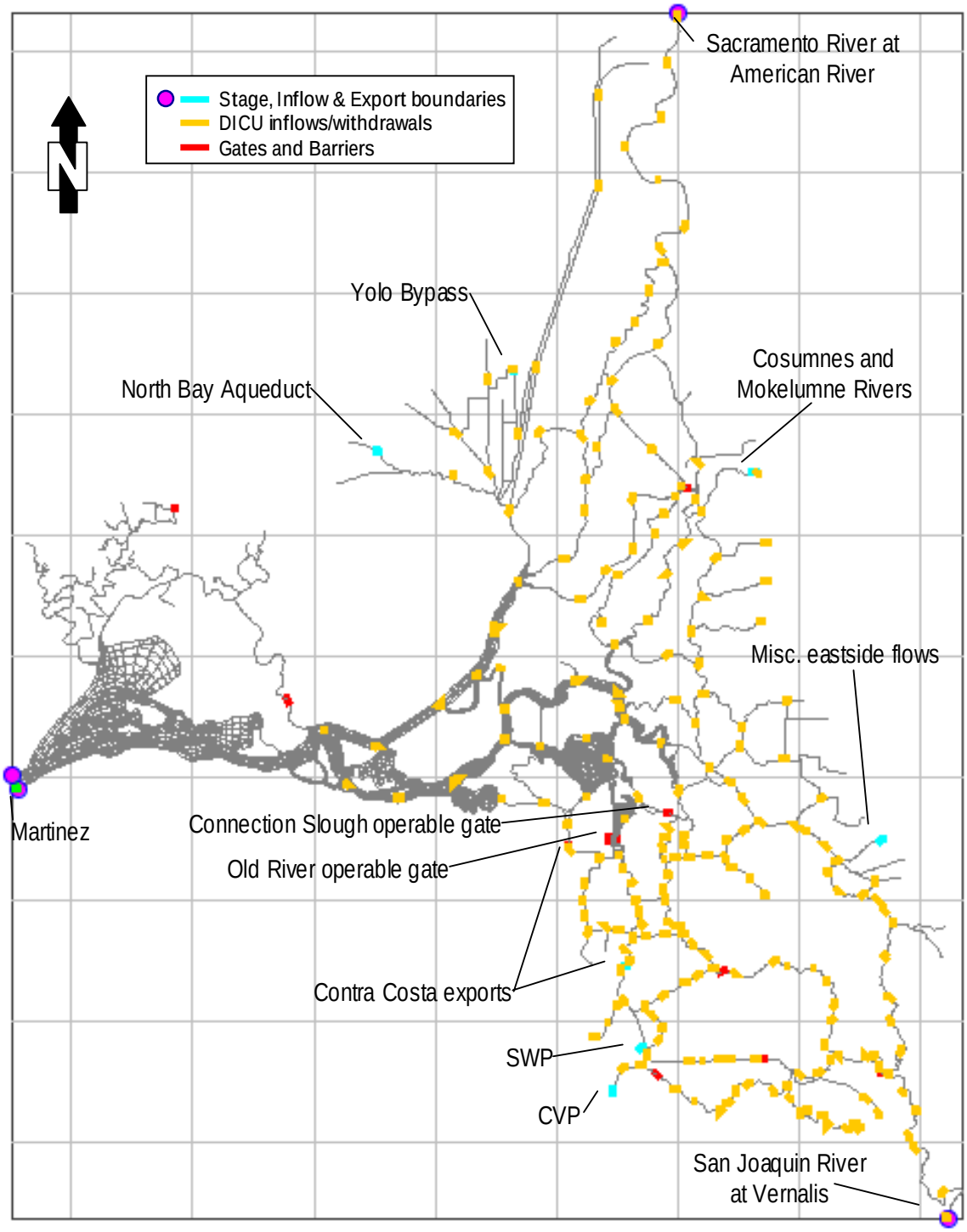

Figure 1 Model grid showing stage, inflow, export, DICU, gate and barrier locations.

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.

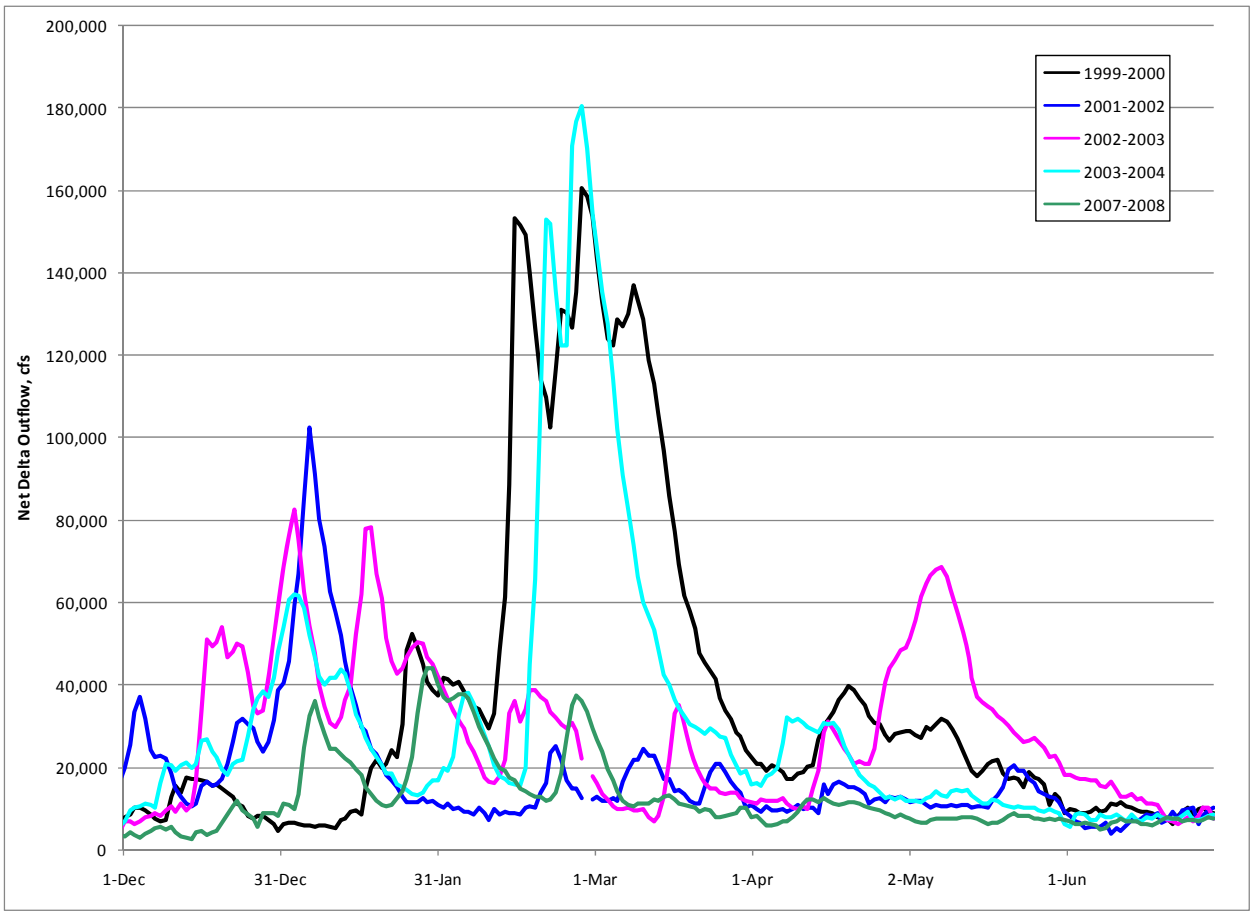

Figure 2 Net Delta Outflow for each December through June simulation period.

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.

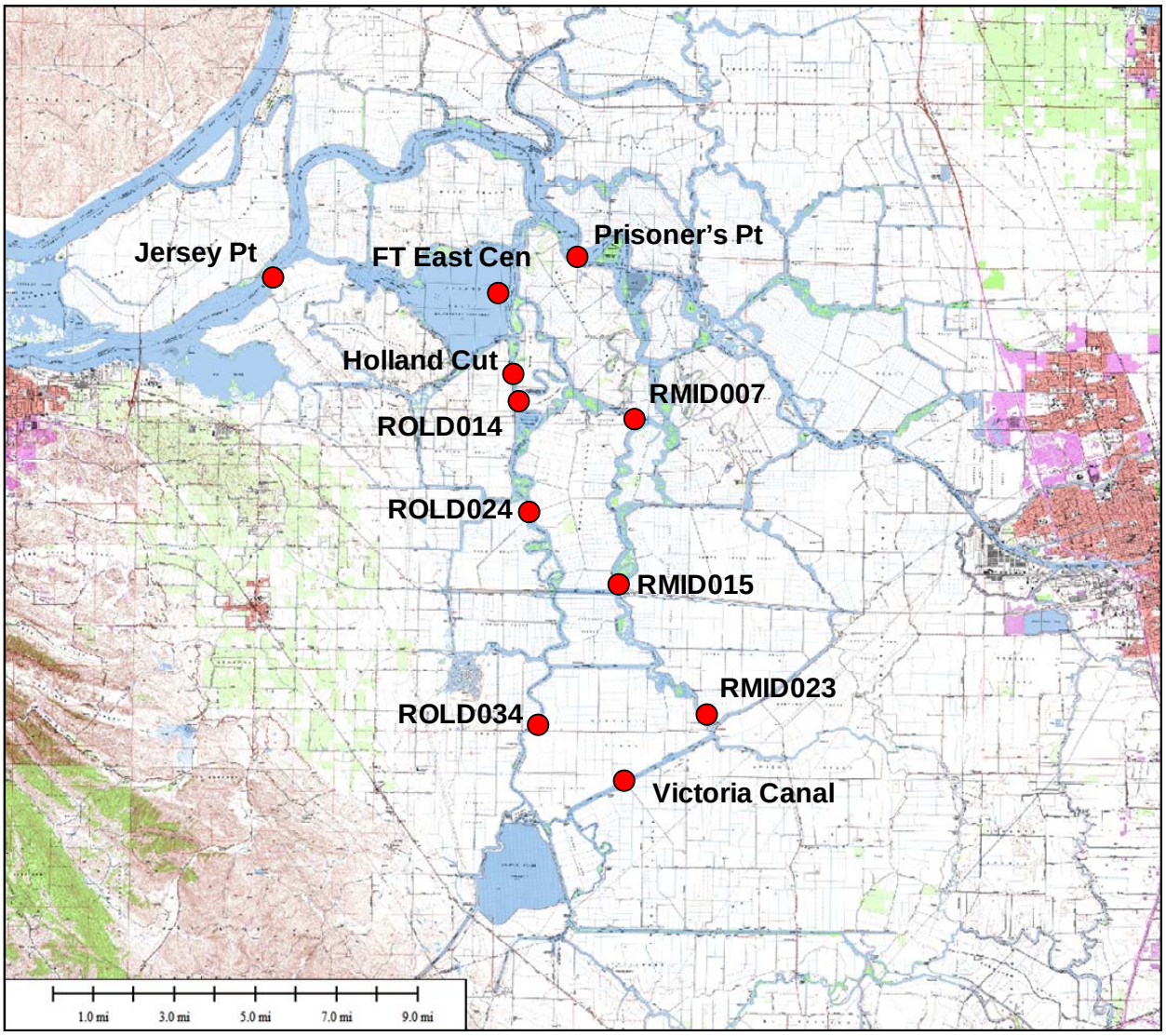

Figure 3 Station location map.

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

Analysis Period	Triggers					
	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

Analysis Period	Final Schedule			
	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.

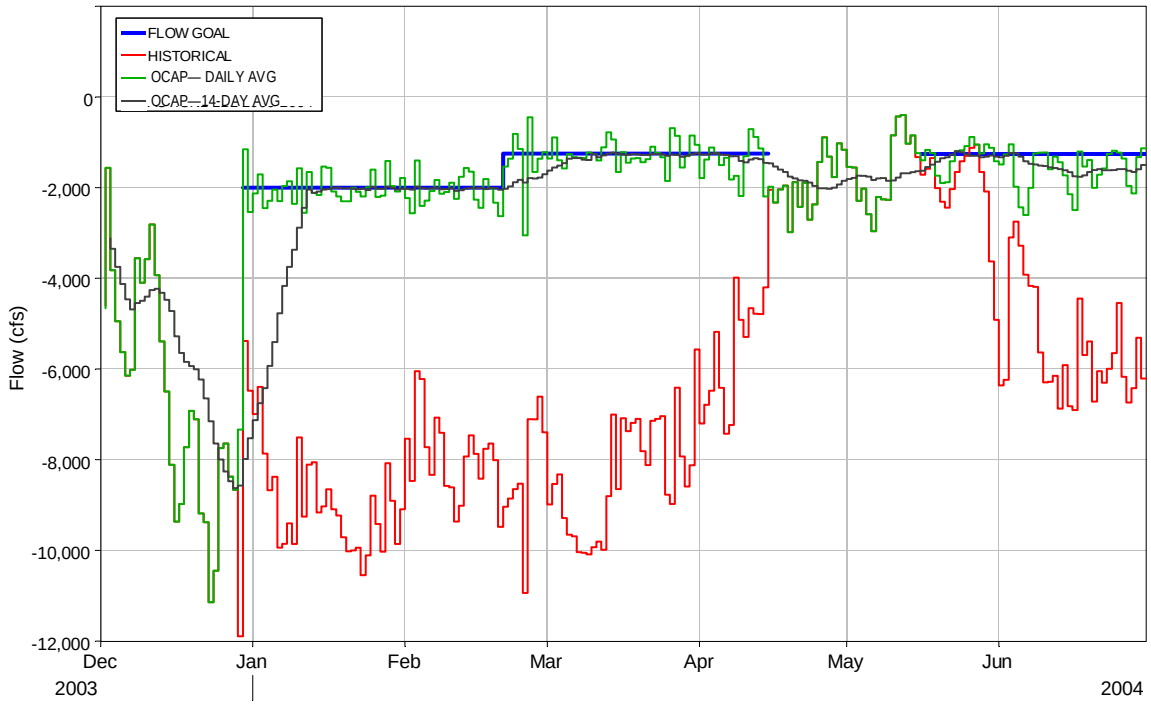

Figure 4 Simulated historical and OCAP (daily and 14-day average) Old + Middle River flows in comparison with OCAP flow goal for December 2003 - June 2004.

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.

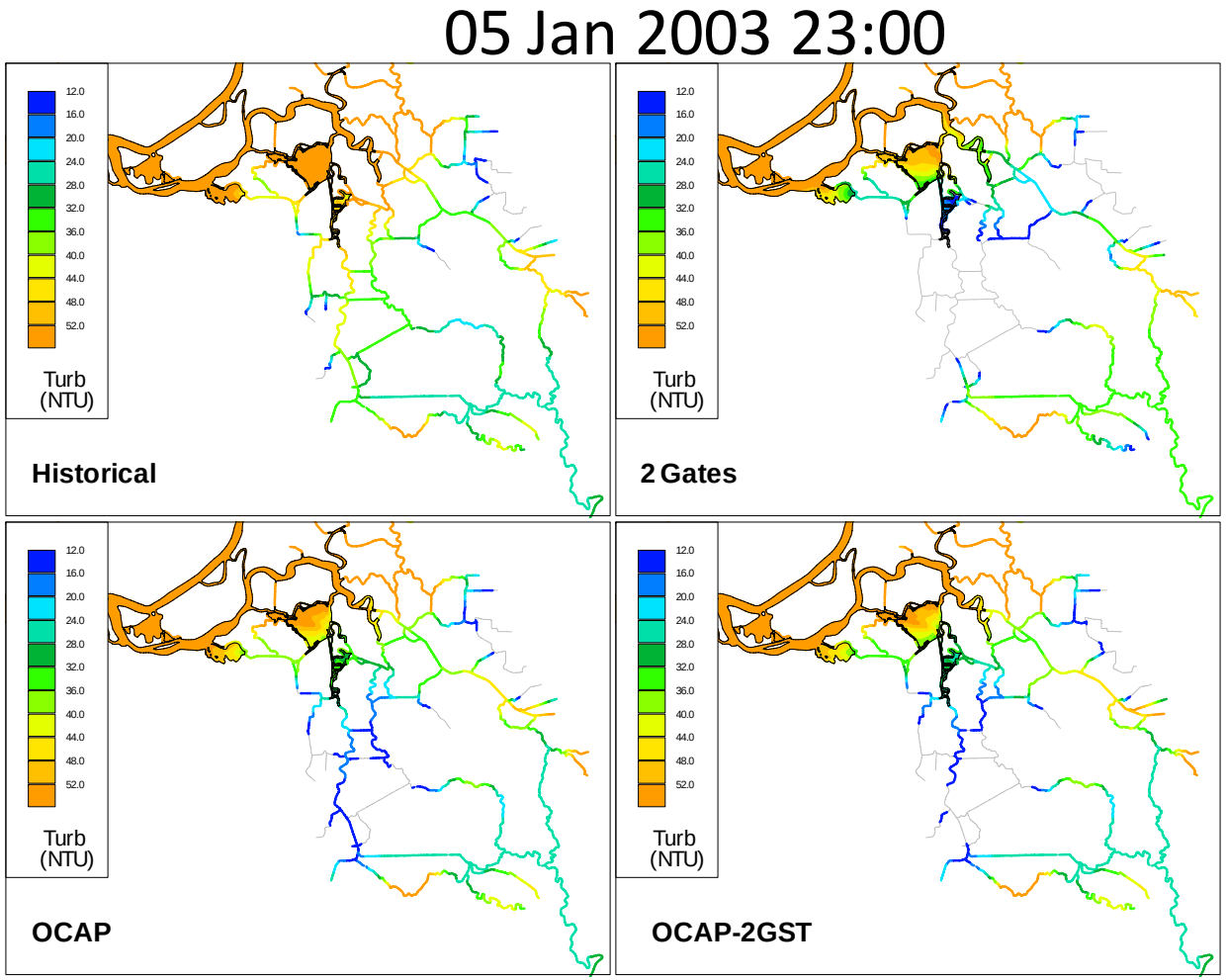

Figure 5 Simulated turbidity for historical conditions, OCAP operations, 2-gate scenario, and OCAP operations with 2-gate start time (OCAP-2GST) on 05 Jan 2003 at 23:00.

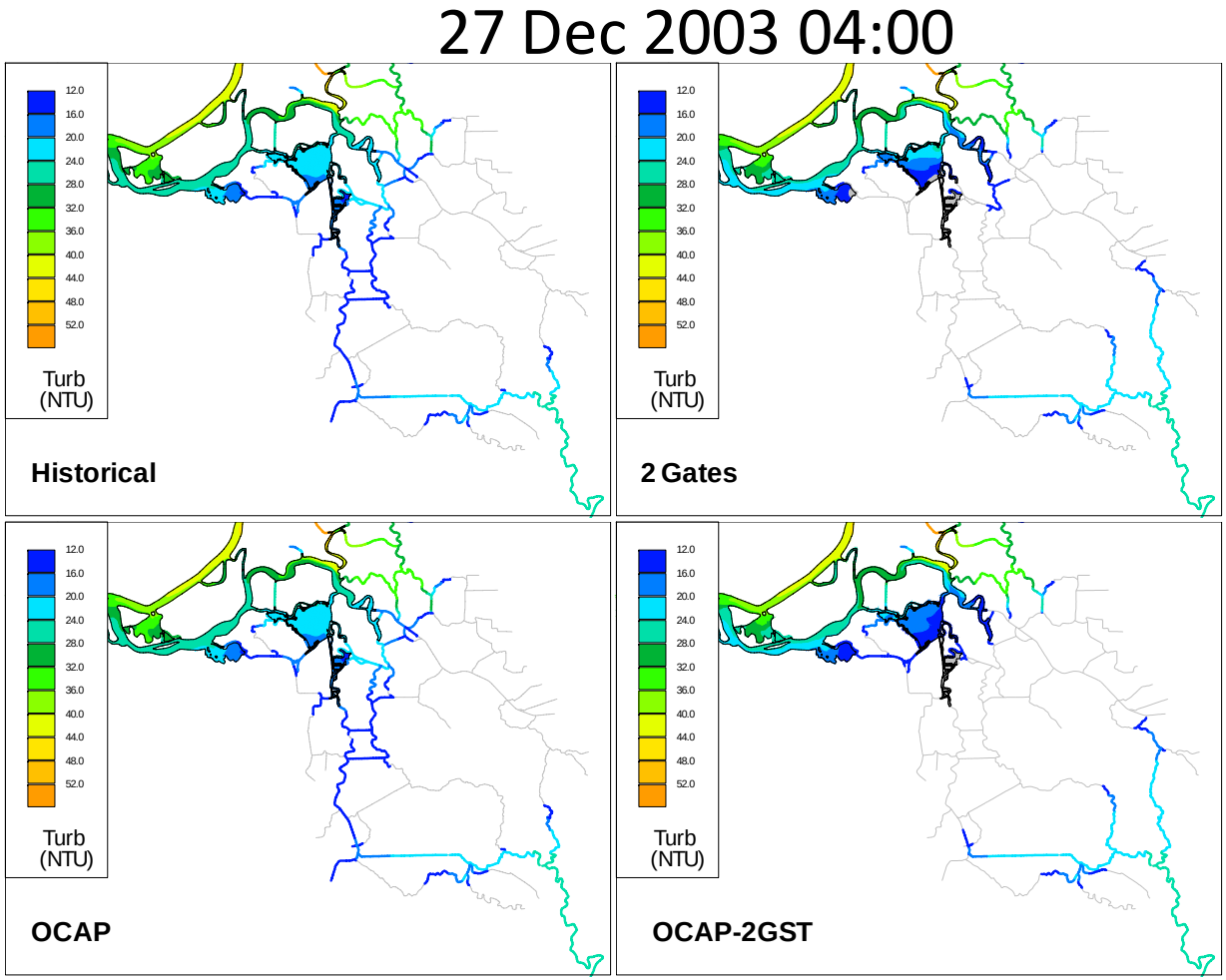

Figure 6 Simulated turbidity for historical conditions, OCAP operations, 2-gate scenario, and OCAP operations with 2-gate start time (OCAP-2GST) on 27 Dec 2003 at 04:00.

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 (2GATE-ALTOP-LB). 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.

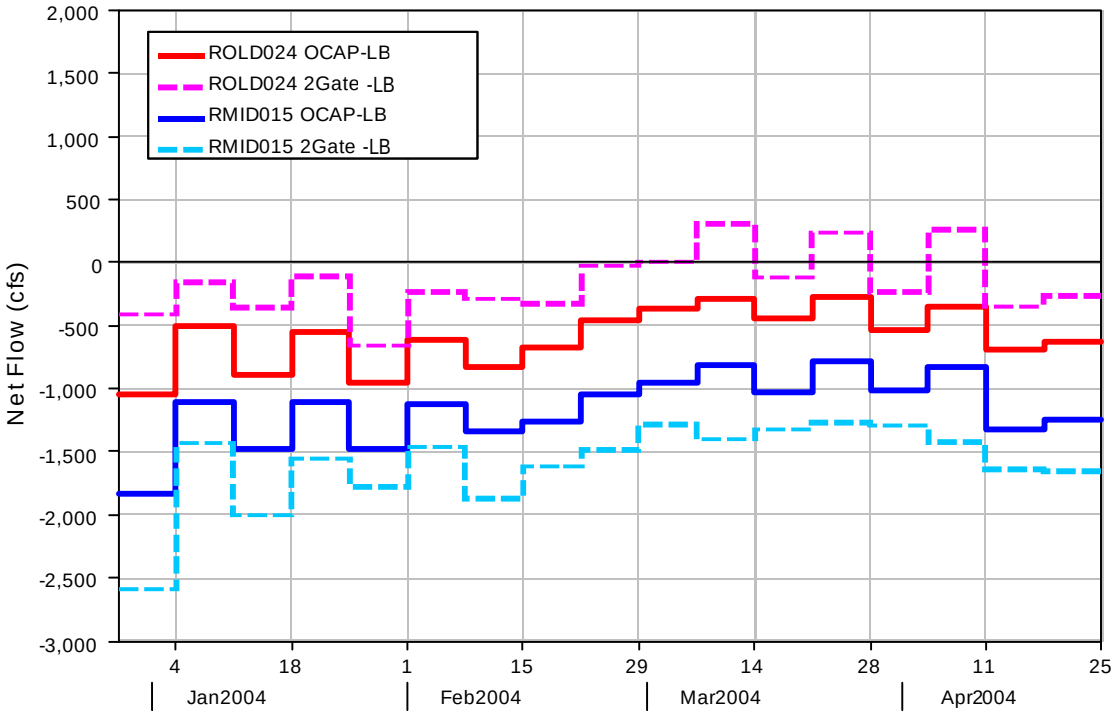

Figure 7 Net flow on Old and Middle Rivers at Bacon Island for no gates (OCAP-LB2) and the "balanced" gate operation (2Gate-OCAP-LB2).

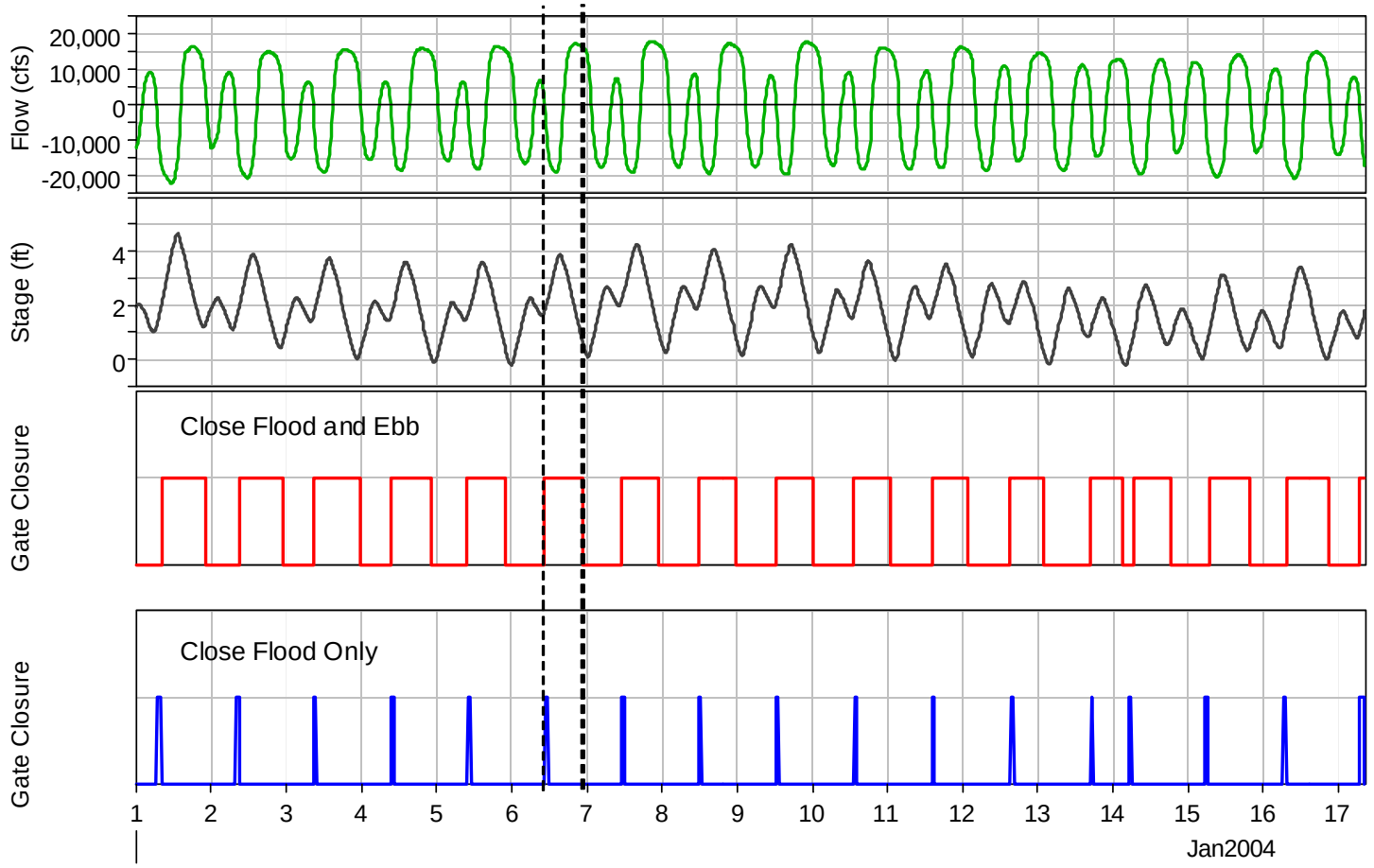

Figure 8 Old River gate operations employed to divert net flow from Old River. The "Close Flood and Ebb" and "Close Flood Only" operations reduce the Old River net flow approximately same degree.

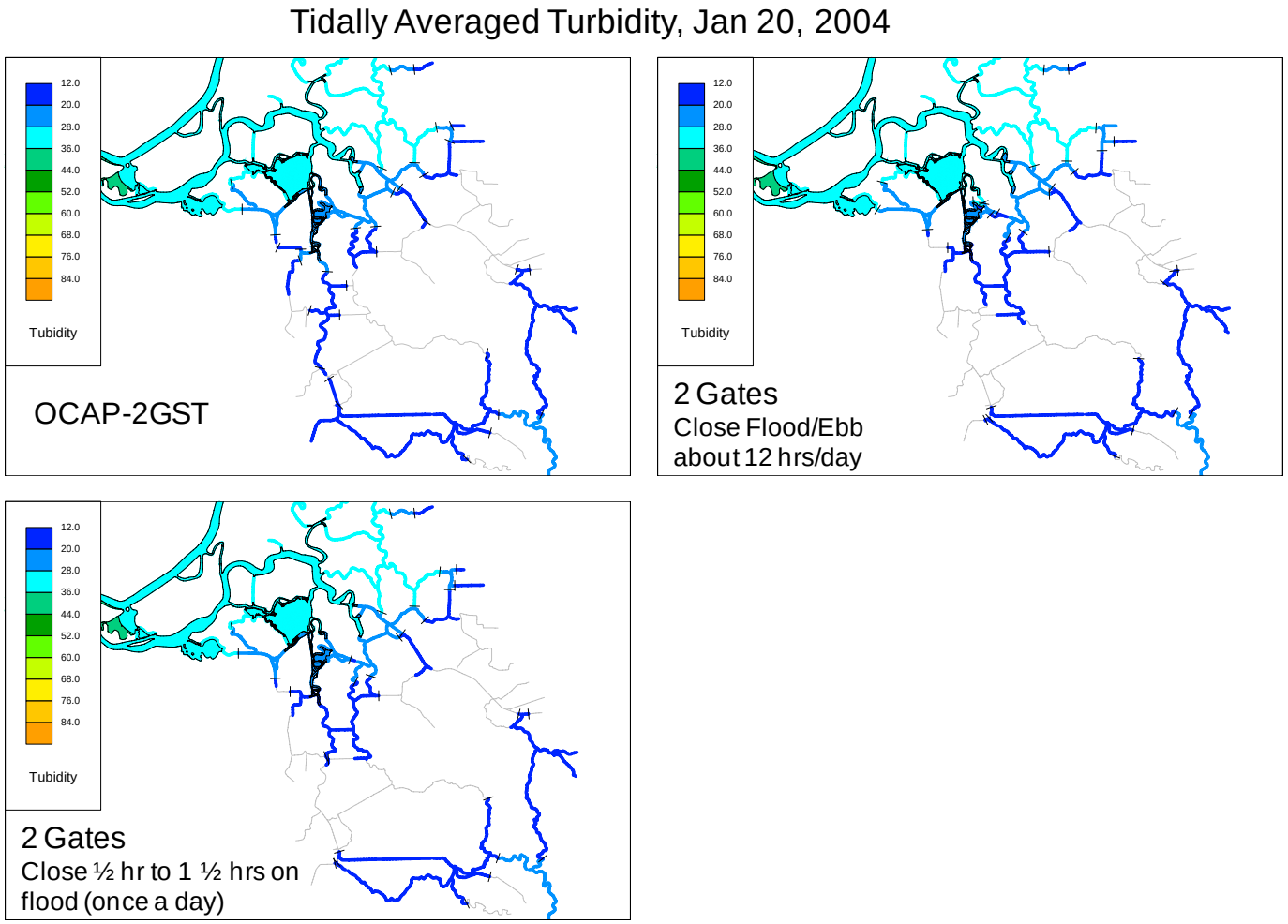

Figure 9 Comparison of simulated turbidity for OCAP operations with 2-gate start time (OCAP-2GST), and the 2-gate scenario with OCAP-2GST conditions. The 2-gate results compare Old River gate closure over the flood/ebb period (12 hrs/day) and for a more limited closure time (½ to 1½ hrs/day on flood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

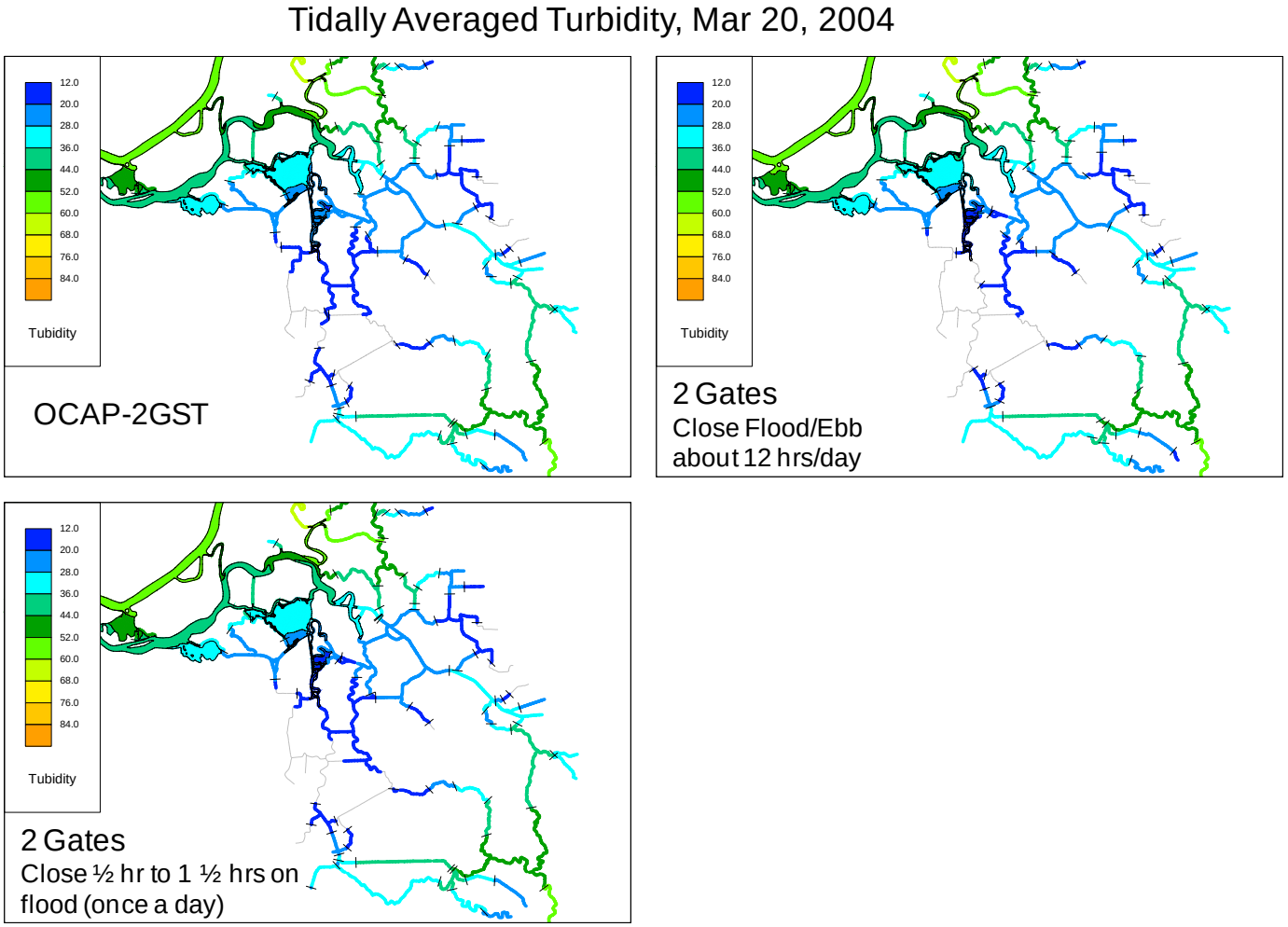

Figure 10 Comparison of simulated turbidity for OCAP operations with 2-gate start time (OCAP-2GST), and the 2-gate scenario with OCAP-2GST conditions. The 2-gate results compare Old River gate closure over the flood/ebb period (12 hrs/day) and for a more limited closure time (½ to 1½ hrs/day on flood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

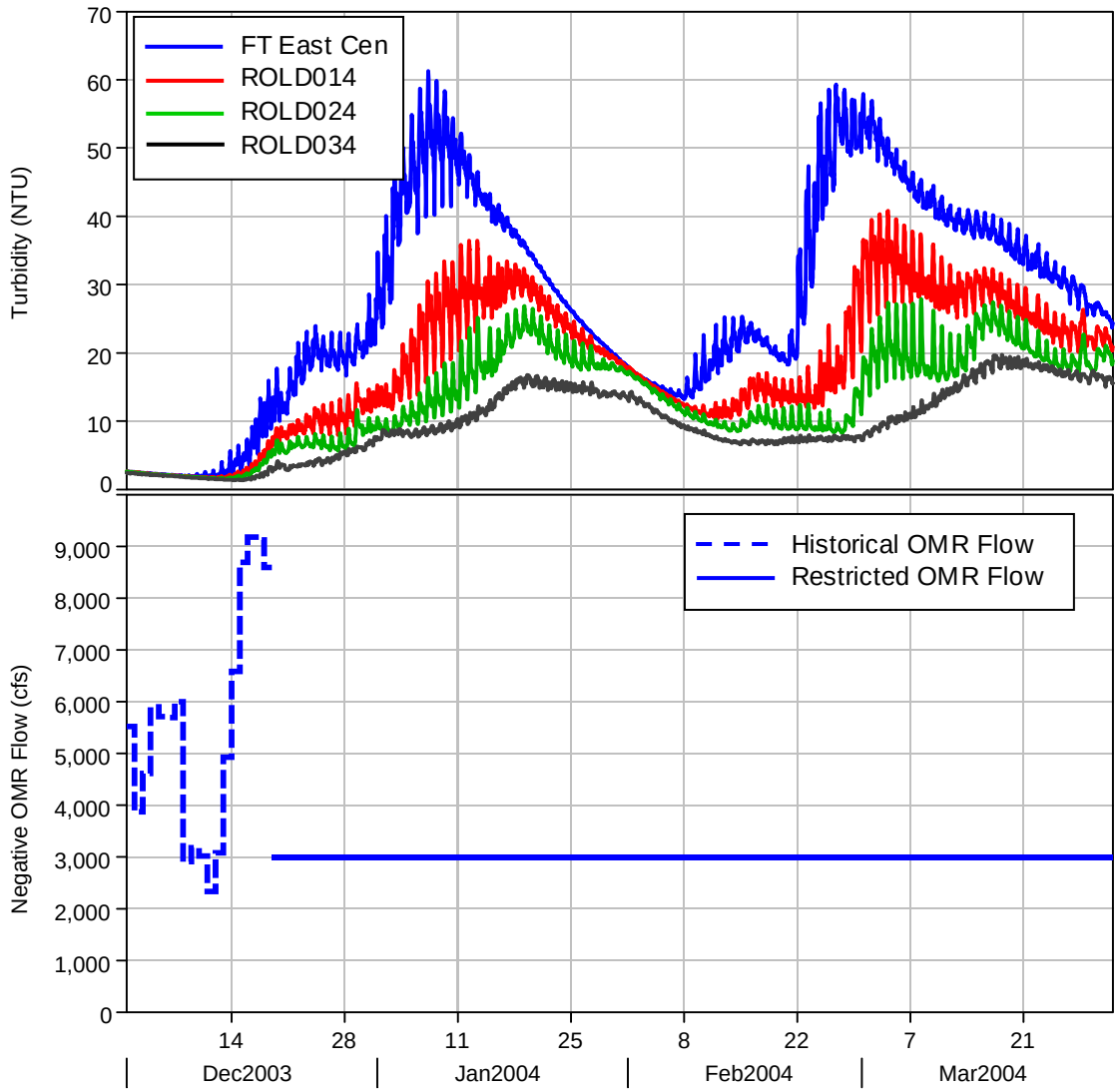

Figure 11 Simulation turbidity time series (top) for 2003-2004 2-gate scenario, with OMR flows at -3000 cfs from Dec 19, 2003 to Mar 31, 2004 (flows shown in bottom plot).

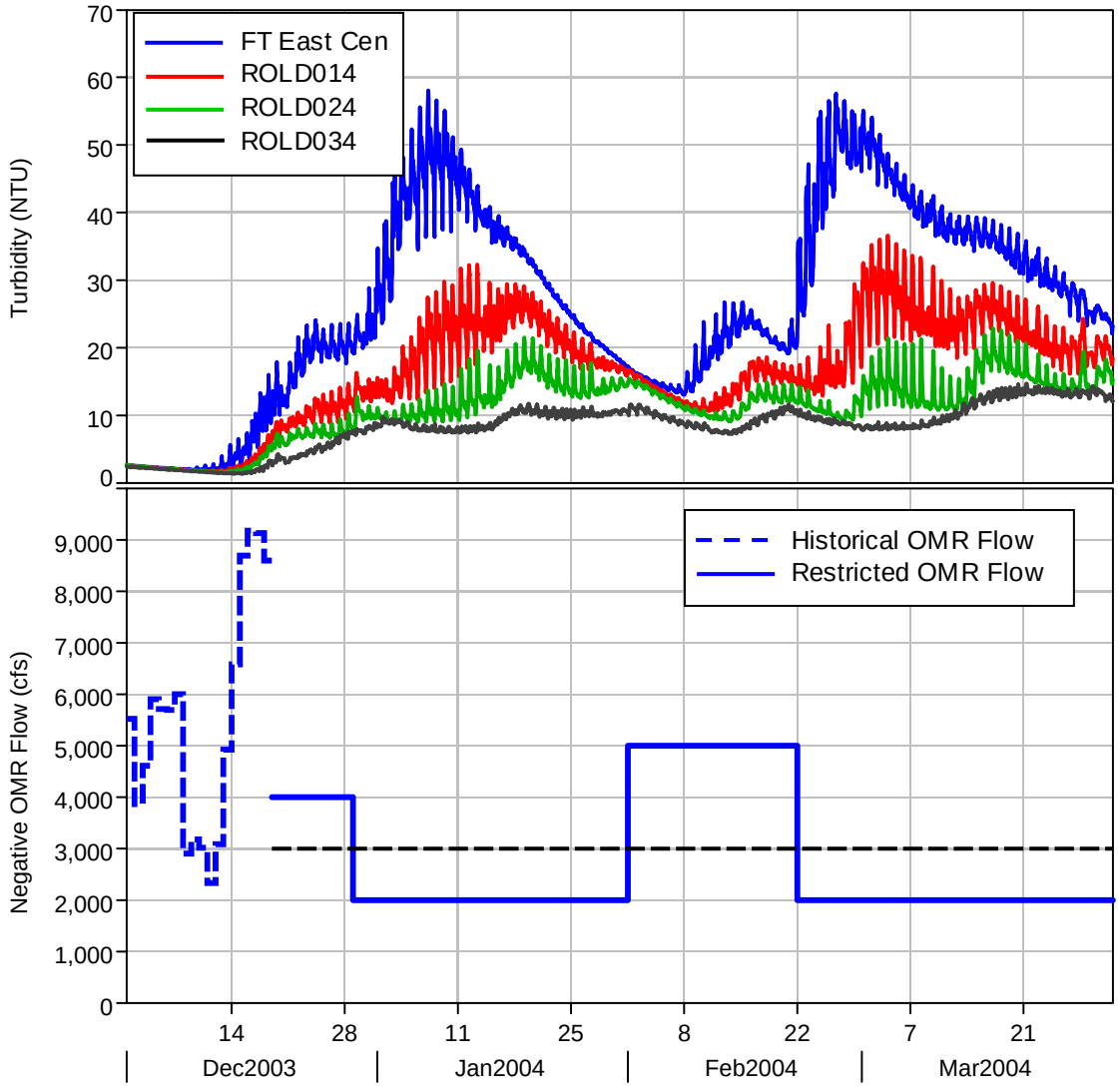

Figure 12 Simulation turbidity time series (top) for 2003-2004 2-gate scenario, with OMR flow restrictions beginning Dec 19, 2003. OMR flows were decreased when Franks Tract turbidity was high and increased when Franks Tract turbidity was low (flows shown in bottom plot).

Salinity Impacts

To analyze salinity impacts, results from three simulations were compared: HIST, OCAP-LB, 2GATE-ALTOP-LB. Run descriptions for the HIST (historical) and OCAP-LB (OCAP lower bound simulation) can be found in Table 6. The 2GATE-ALTOP-LB simulation is a 2-gate lower bound run with the Connection Slough gate always closed. During the adult period (December through February) the Old River gate is closed ½ to 1½ hours per day during the flood tide (as described in the Gate Optimization section above). During the larval/juvenile period (March through June), the Old River gate operates tidally, open on ebb. Note that no adult or larval/juvenile particle tracking runs were performed for this 2-gate simulation.

Two additional runs were made to test the sensitivity of salinity impact to gate closure time during the adult operation period. For the CONNECTION CLOSED simulation, the connection Slough gate was left closed but the Old River gate always open. This reduces the changes in net Old River/Middle River flow to about 1/3 of the "2GATE-ALTOP-LB" operation. For the 2GATE_ALTOP_REDUCED simulation, the connection Slough gate is closed, and closure time on Old River gate by 1/2. This reduces the changes in net Old River/Middle River flow to about 2/3 of the "2GATE-ALTOP-LB" operation. For both of these runs the gate operation during the juvenile period was the same as the "2GateE-ALTOP-LB" run. As expected, the sensitivity runs show that salinity impacts during the adult period can be modulated by reduced operation of the gates.

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 small additional changes in salinity south of the gates during the adult period. During the larval/juvenile period, gate operations tend to lessen the salinity impact of OCAP export reductions at locations south of ROLD024, while causing additional salinity increases closer and to the north of the gates. Example plots of computed tidally averaged EC (a surrogate for salinity) are shown in Figure 13 through Figure 22 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 tidally averaged EC is as much as 200 umhos/cm higher than historical. When the Old River gate switches to larval/juvenile operations in March, the open on ebb operation causes the 2GATE-ALTOP-LB EC to spike to 380 umhos/cm above historical at ROLD014. Within the month the EC drops back down to around 30 umhos/cm above the OCAP-LB case, as the area to the south freshens. At RMID007, at the onset of the larval/juvenile operation, the 2GATE-ALTOP-LB EC drops well below the OCAP-LB result, and even below historical during May.

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. At the beginning of the larval/juvenile period, the 2GATE-

ALTOP-LB result is as much as 370 umhos/cm higher than historical. From April through June, the OCAP-LB and 2GATE-ALTOP-LB results are similar. Further upstream at ROLD034 (Figure 16), the OCAP and 2GATE tidally averaged EC results are as much as 350 umhos/cm higher than historical. The 2GATE results drops below the OCAP result from March through June, and below the historical result during May.

At RMID023 (Figure 17) during March, the OCAP tidally averaged EC result is as much as 340 umhos/cm higher than historical. The 2GATE-ALTOP-LB result is very similar to the OCAP-LB result during the adult period and drops dramatically at the onset of the larval/juvenile period, falling below historical by the end of April.

Results at the CVP and SWP exports are shown in Figure 18 and Figure 19. The OCAP-LB and 2GATE-ALTOP-LB results are similar at these locations during the adult period, with the 2GATE alternative EC being slightly higher. At the CVP the alternative simulations resulted in salinity increases at the exports as high as 300 umhos/cm. At the SWP the increases are as high as 430 umhos/cm. During the larval/juvenile period, the 2GATE EC decreases below OCAP, falling below historical during May.

In Victoria Canal at the proposed Contra Costa Water District intake, shown in Figure 20, OCAP EC is as much as 350 umhos/cm higher than observed. The 2GATE EC is similar to the OCAP result during the adult period and then declines at the onset of the larval/juvenile period, falling below historical by the end of April.

Impacts further downstream are illustrated in Figure 21 and Figure 22 at Franks Tract and Jersey Point, respectively. At these locations, OCAP-LB and 2GATE-ALTOP-LB EC results are similar during the adult period. When larval/juvenile operation begins in March, the 2GATE result increases and then remains slightly higher than OCAP for the remainder of the simulation.

Representative color contour plots of EC from the Historical, OCAP-LB and 2GATE-ALTOP-LB simulations on February 1, 2004 and May 1, 2004 are shown in Figure 23 and Figure 24. On February 1, during the adult period, the contours show that the reduced exports of the OCAP and 2GATE simulations allow higher EC San Joaquin water to dominate the south Delta. On May 1, during the larval/juvenile period, the contours show that the gate operations circulate fresher water into the south Delta, countering the effect of the reduced exports.

Overall, adult period gate operations can have a minor negative impact on salinity in the Old River by transferring net flow to Middle River. The adult period gate operations can be modulated to reduce this impact if required, however at the expense of reduced effectiveness in balancing the turbidity flux.

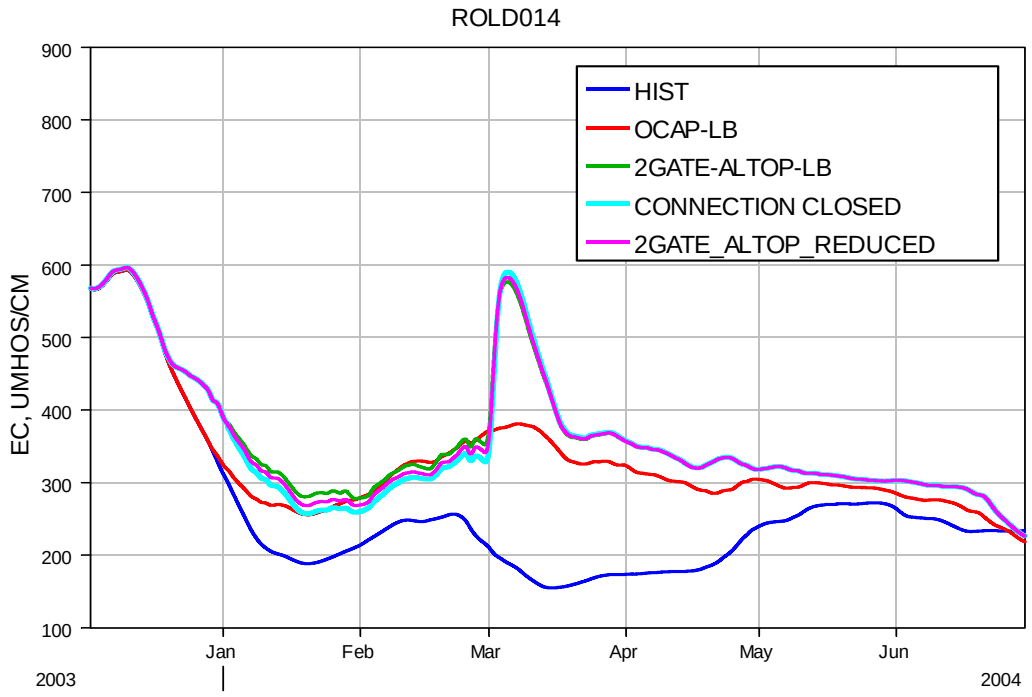

Figure 13 Tidally averaged EC at ROLD014 for the 2003-2004 simulation period for HIST, OCAP-LB and 2GATE-ALTOP-LB, CONNECTION CLOSED and 2GATE_ALTOP_REDUCED simulations.

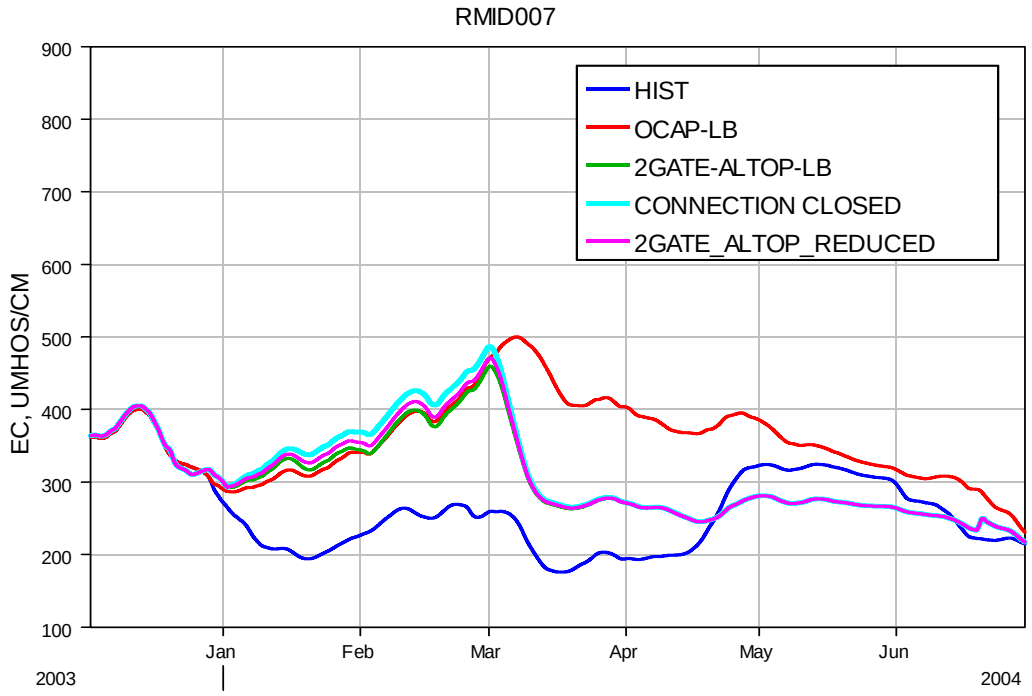

Figure 14 Tidally averaged EC at RMID007 for the 2003-2004 simulation period for HIST, OCAP-LB and 2GATE-ALTOP-LB, CONNECTION CLOSED and 2GATE_ALTOP_REDUCED simulations.

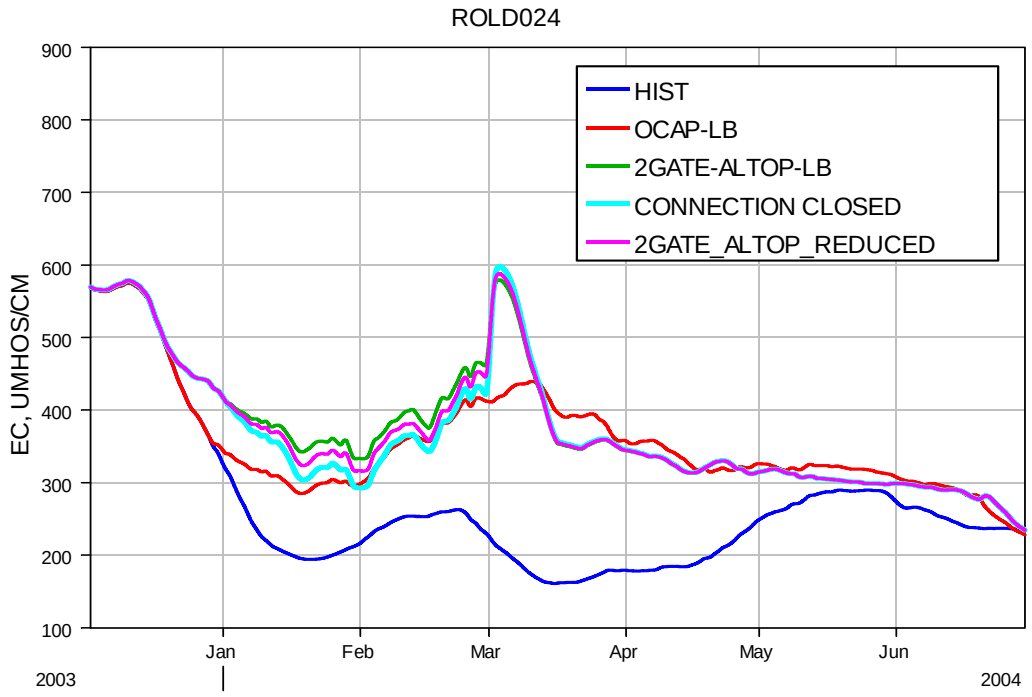

Figure 15 Tidally averaged EC at ROLD024 for the 2003-2004 simulation period for HIST, OCAP-LB and 2GATE-ALTOP-LB, CONNECTION CLOSED and 2GATE_ALTOP_REDUCED simulations.

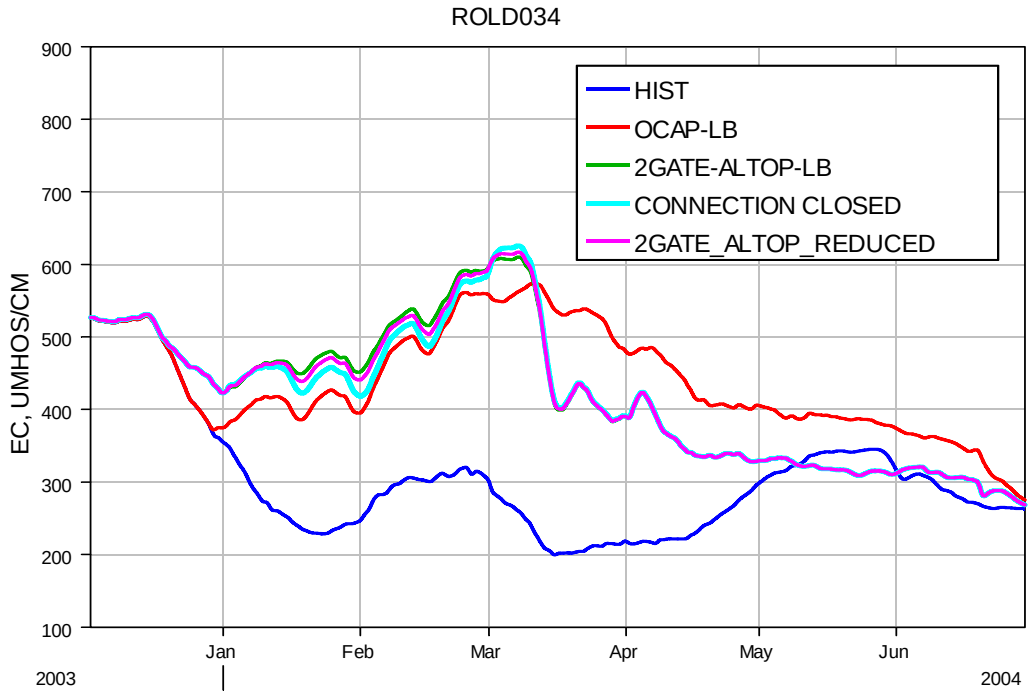

Figure 16 Tidally averaged EC at ROLD034 for the 2003-2004 simulation period for HIST, OCAP-LB and 2GATE-ALTOP-LB, CONNECTION CLOSED and 2GATE_ALTOP_REDUCED simulations.

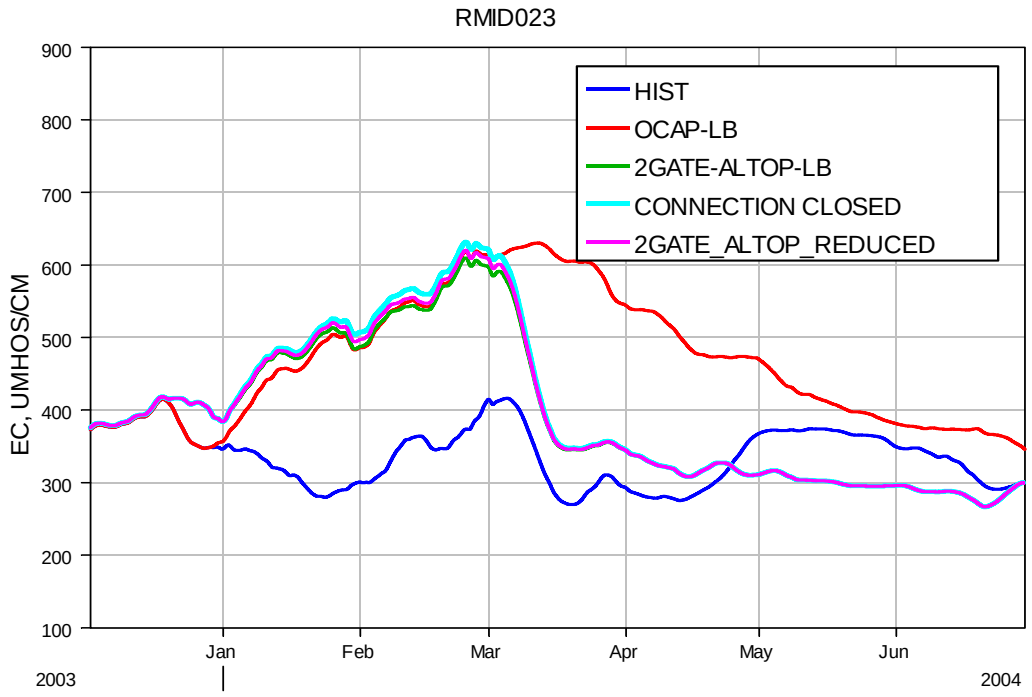

Figure 17 Tidally averaged EC at RMID023 for the 2003-2004 simulation period for HIST, OCAP-LB and 2GATE-ALTOP-LB, CONNECTION CLOSED and 2GATE_ALTOP_REDUCED simulations.

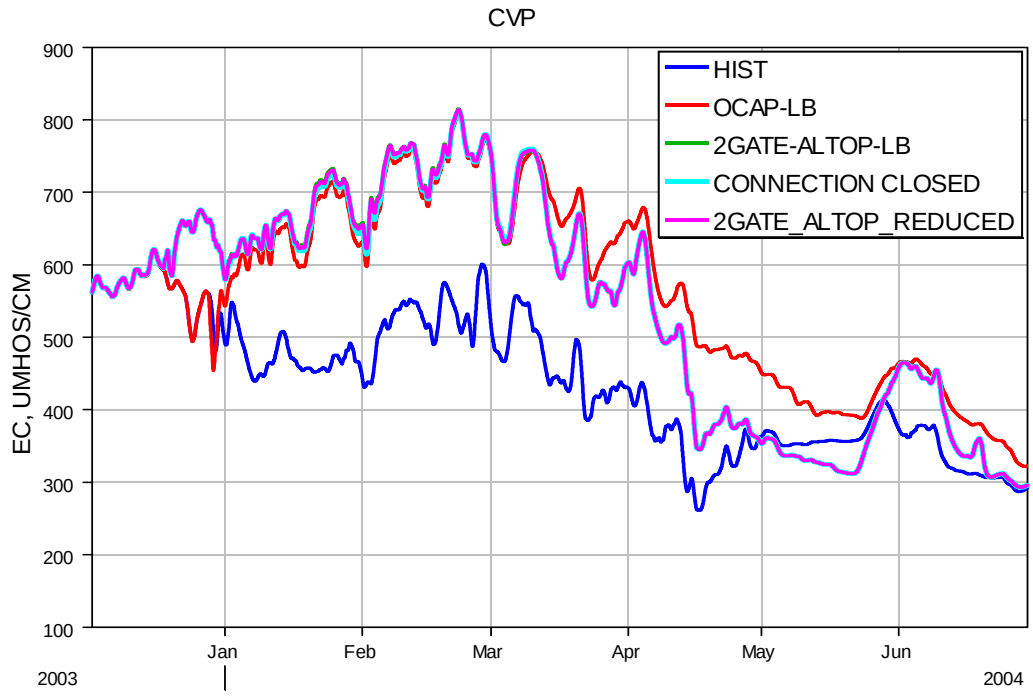

Figure 18 Tidally averaged EC at the CVP for the 2003-2004 simulation period for HIST, OCAP-LB and 2GATE-ALTOP-LB, CONNECTION CLOSED and 2GATE_ALTOP_REDUCED simulations.

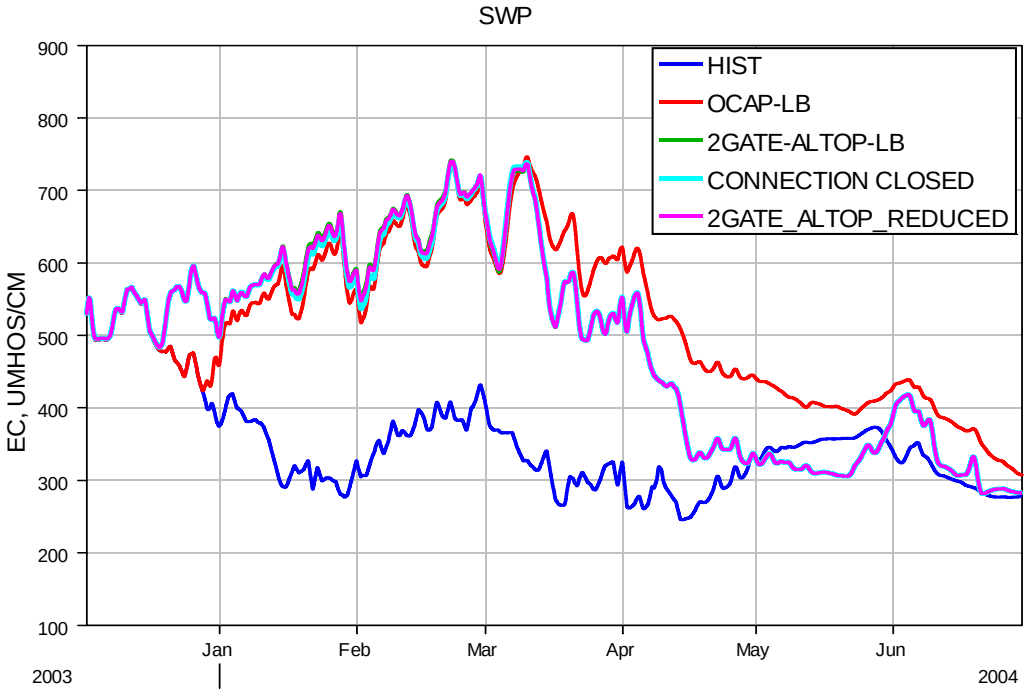

Figure 19 Tidally averaged EC at the SWP for the 2003-2004 simulation period for HIST, OCAP-LB and 2GATE-ALTOP-LB, CONNECTION CLOSED and 2GATE_ALTOP_REDUCED simulations.

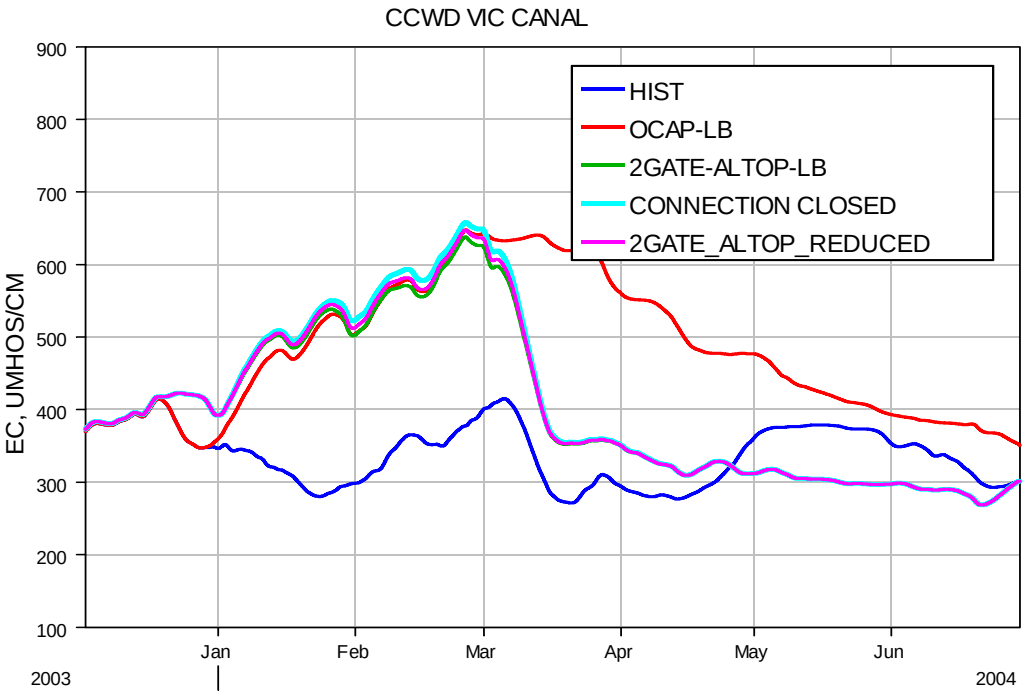

Figure 20 Tidally averaged EC at Victoria Canal at the proposed CCWD intake location for the 2003-2004 simulation period for HIST, OCAP-LB and 2GATE-ALTOP-LB, CONNECTION CLOSED and 2GATE_ALTOP_REDUCED simulations.

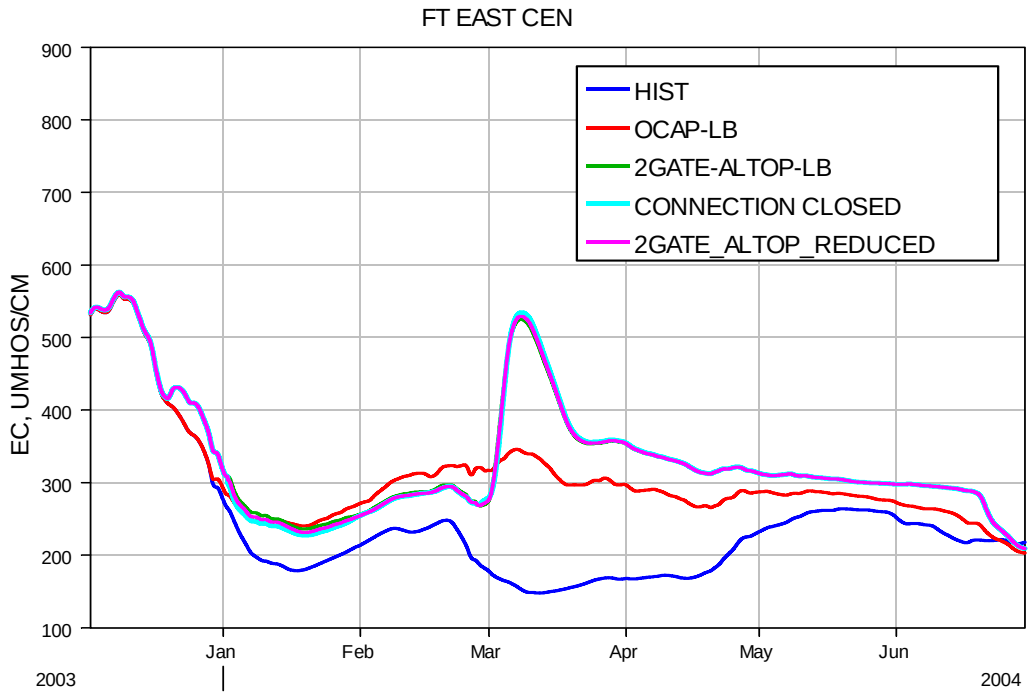

Figure 21 Tidally averaged EC in Franks Tract for the 2003-2004 simulation period for HIST, OCAP-LB and 2GATE-ALTOP-LB, CONNECTION CLOSED and 2GATE_ALTOP_REDUCED simulations.

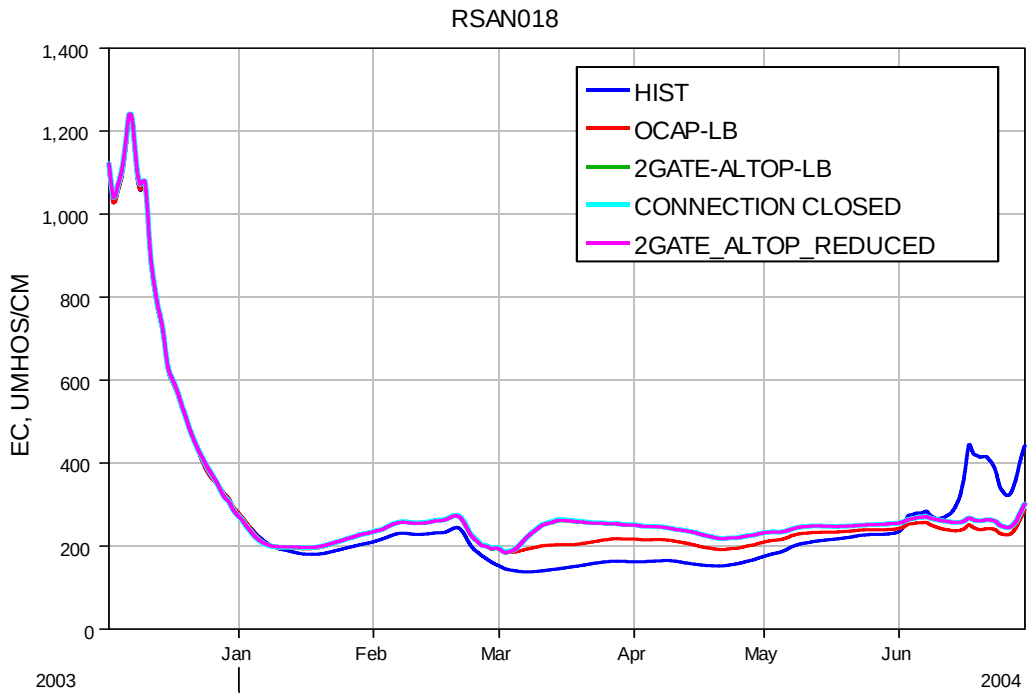

Figure 22 Tidally averaged EC at the Jersey Point (RSAN018) for the 2003-2004 simulation period for HIST, OCAP-LB and 2GATE-ALTOP-LB, CONNECTION CLOSED and 2GATE_ALTOP_REDUCED simulations.

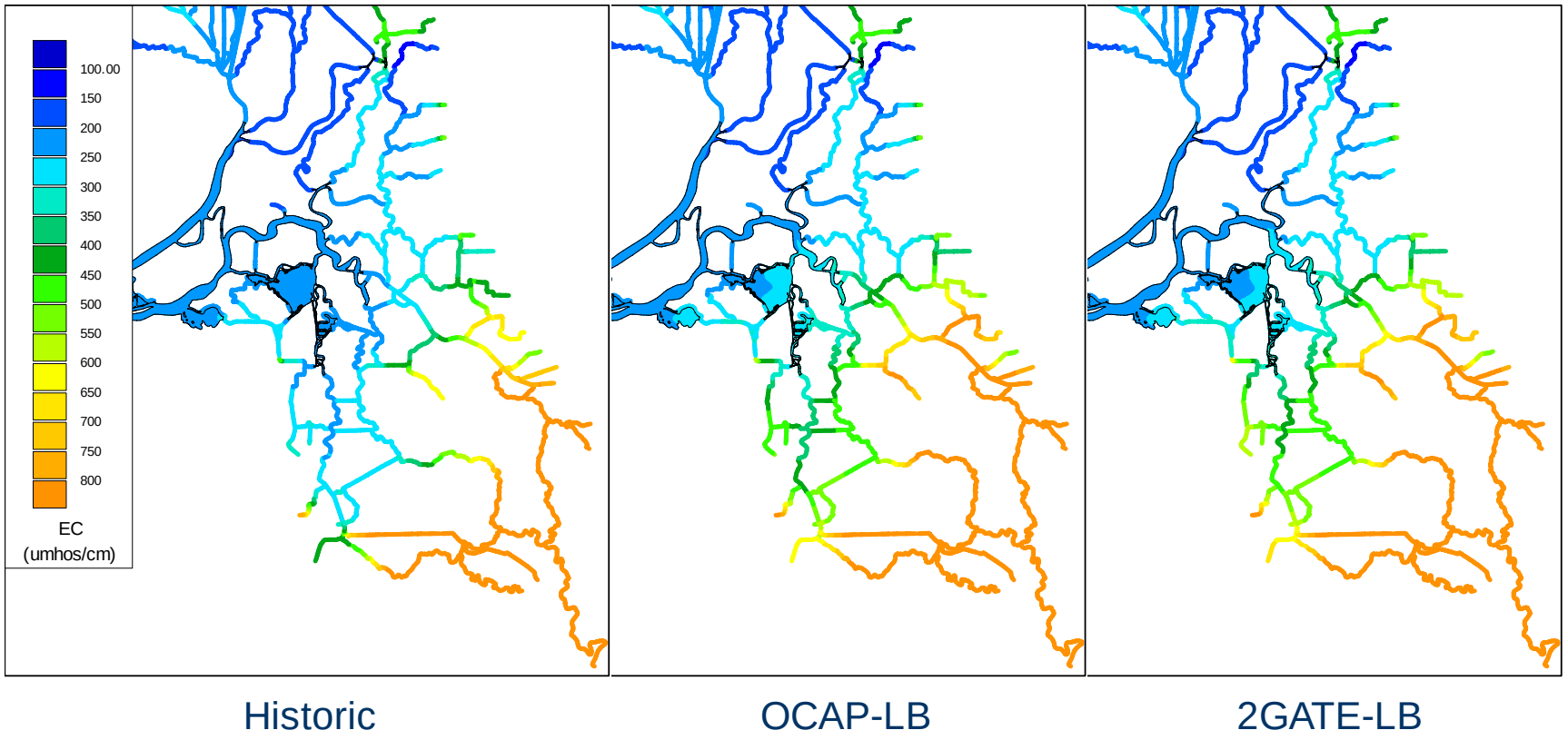

Figure 23 EC contours on February 1, 2004 (during the adult operation period) for Historic, OCAP-LB and 2GATE-LB simulations.

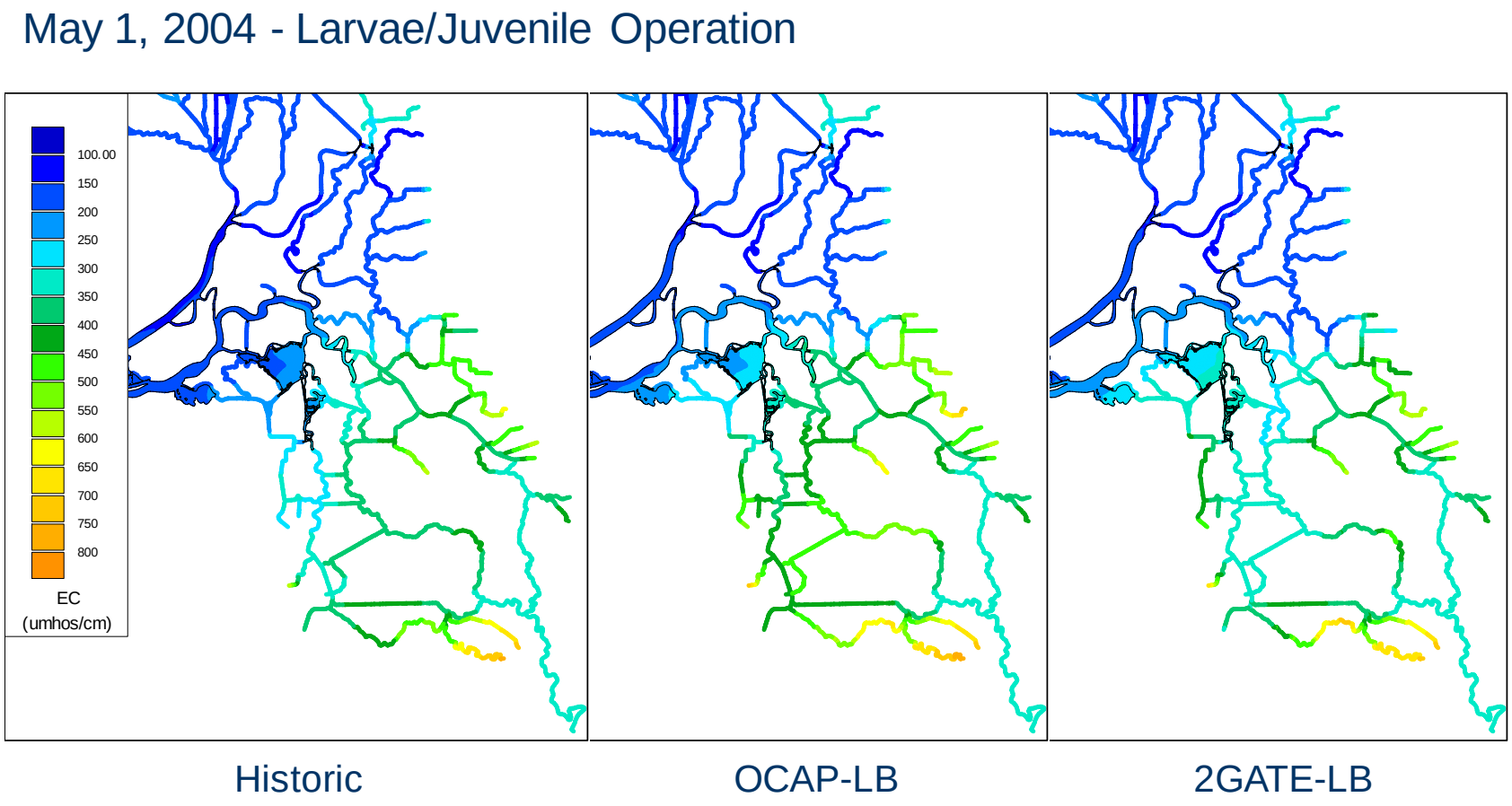

Figure 24 EC contours on May 1, 2004 (during the larvae/juvenile operation period) for Historic, OCAP-LB and 2GATE-LB simulations.

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 25 through Figure 28 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 28) 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

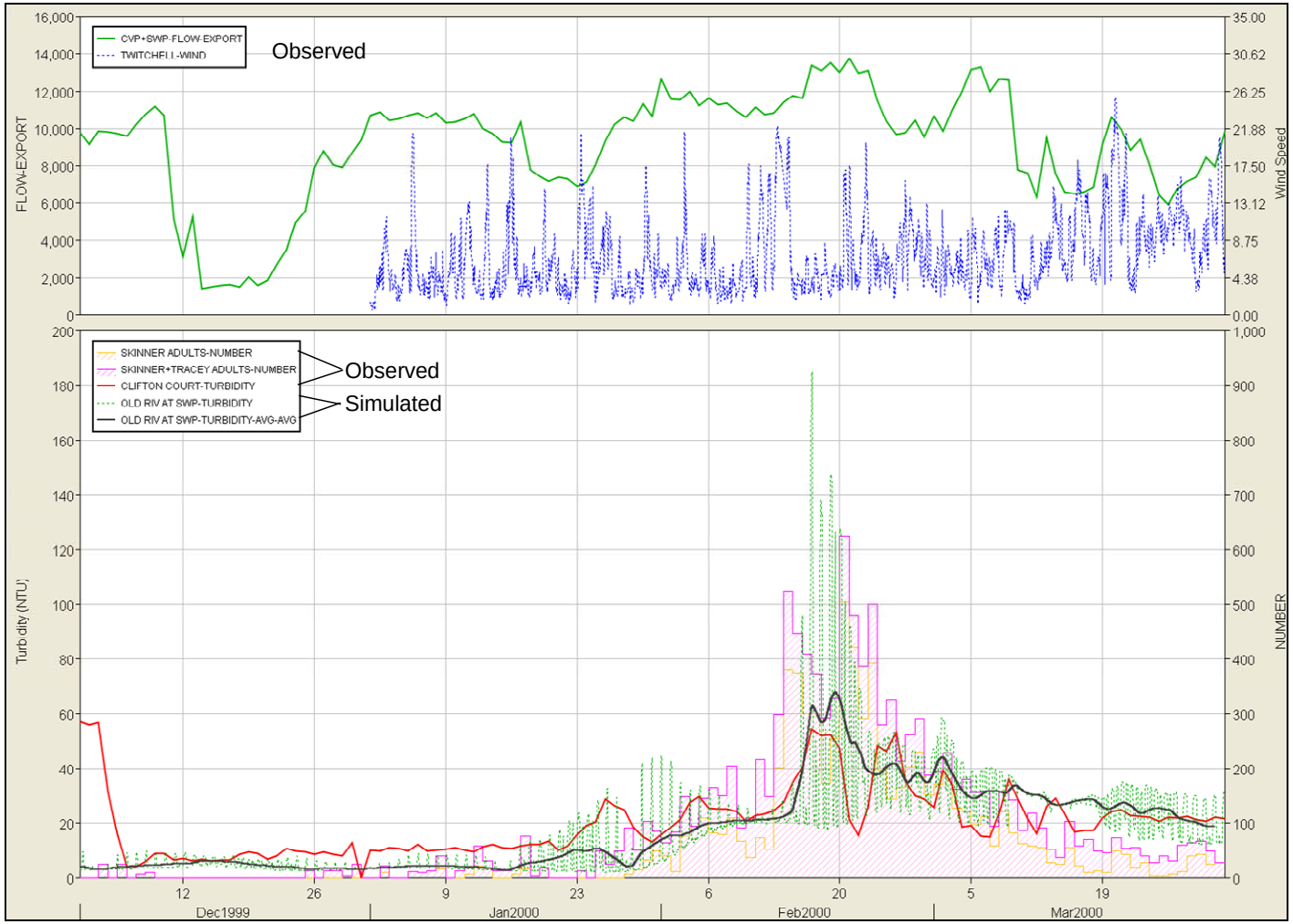

Figure 25 For December 1999 – March 2000: historical exports and Twitchell Island wind speed (above); and observed smelt salvage at Tracy and Skinner, observed Clifton Court turbidity, and computed dynamic and tidally averaged turbidity at the entrance to Clifton Court (below).

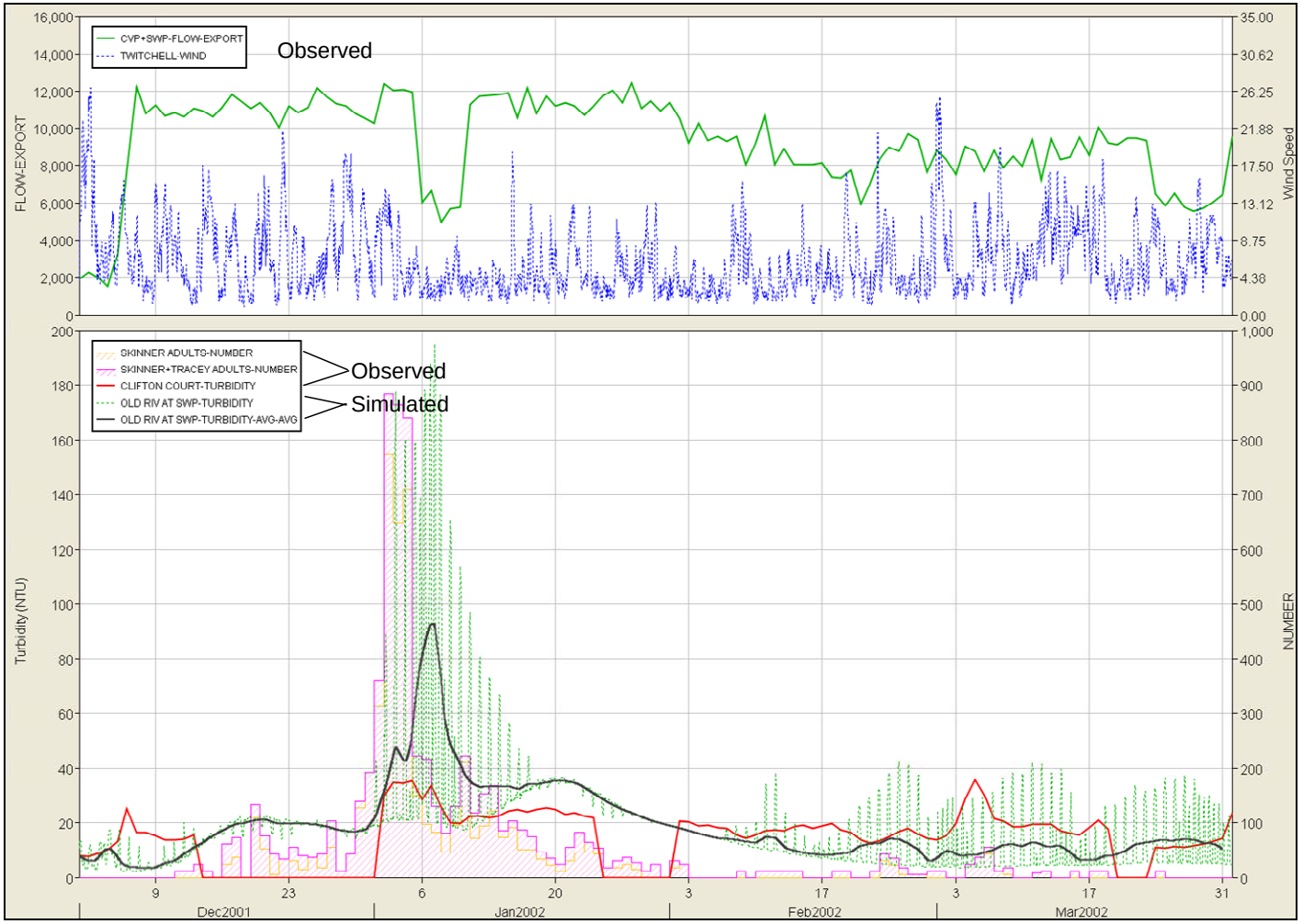

Figure 26 For December 2001 – March 2002: historical exports and Twitchell Island wind speed (above); and observed smelt salvage at Tracy and Skinner, observed Clifton Court turbidity, and computed dynamic and tidally averaged turbidity at the entrance to Clifton Court (below).

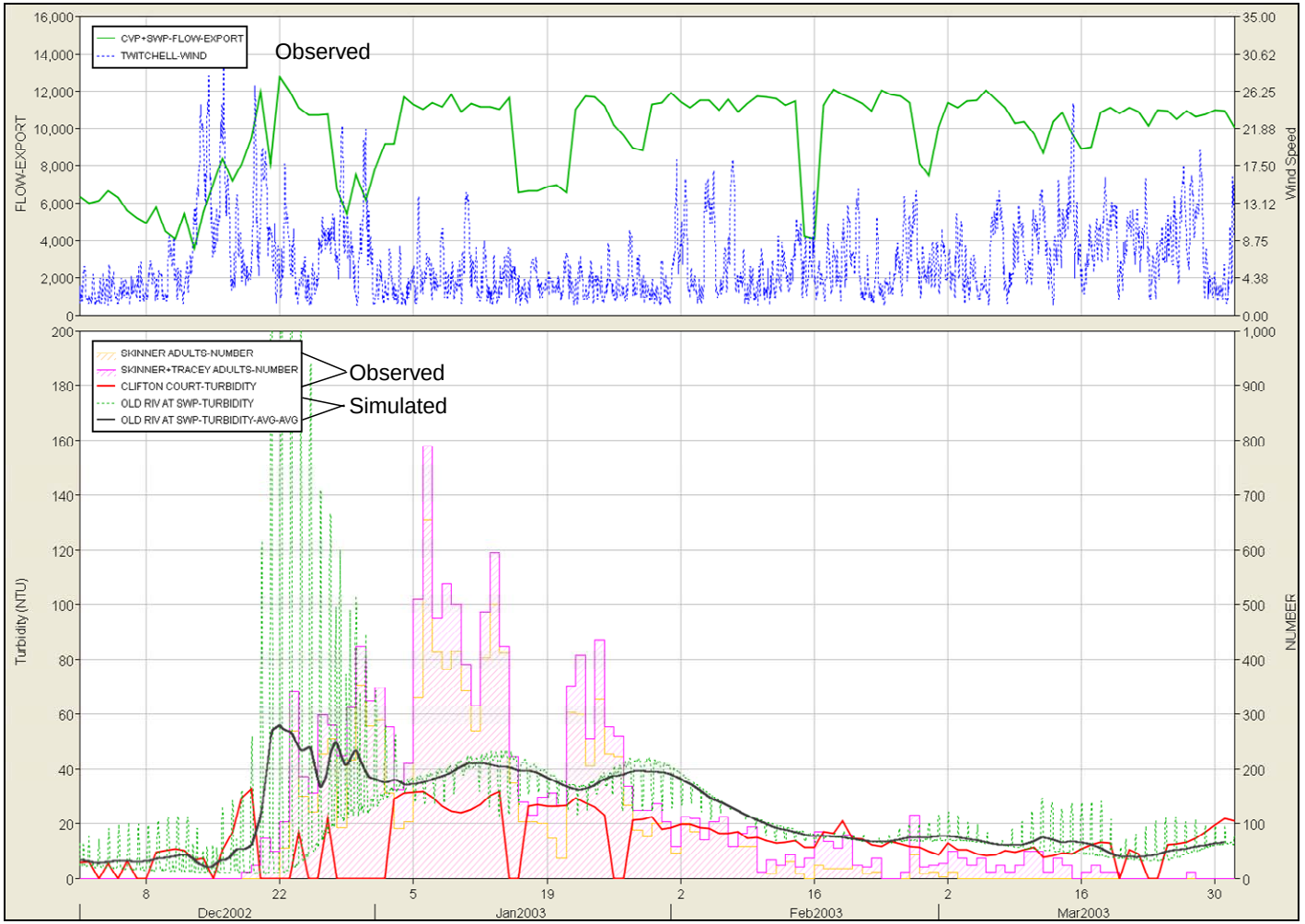

Figure 27 For December 2002 – March 2003: historical exports and Twitchell Island wind speed (above); and observed smelt salvage at Tracy and Skinner, observed Clifton Court turbidity, and computed dynamic and tidally averaged turbidity at the entrance to Clifton Court (below).

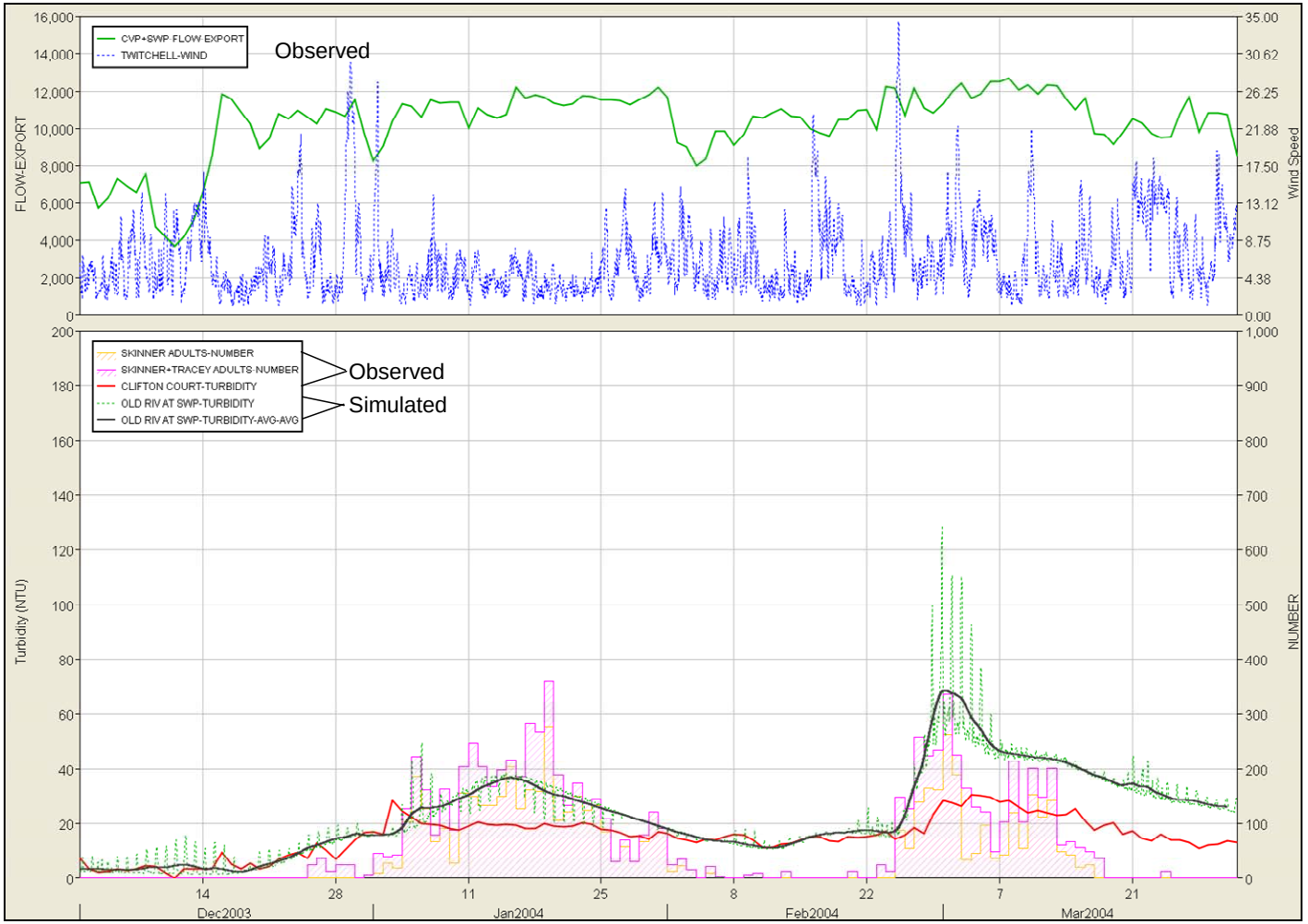

Figure 28 For December 2003 – March 2004: historical exports and Twitchell Island wind speed (above); and observed smelt salvage at Tracy and Skinner, observed Clifton Court turbidity, and computed dynamic and tidally averaged turbidity at the entrance to Clifton Court (below).

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, 1998)

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 29 through Figure 32) 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.

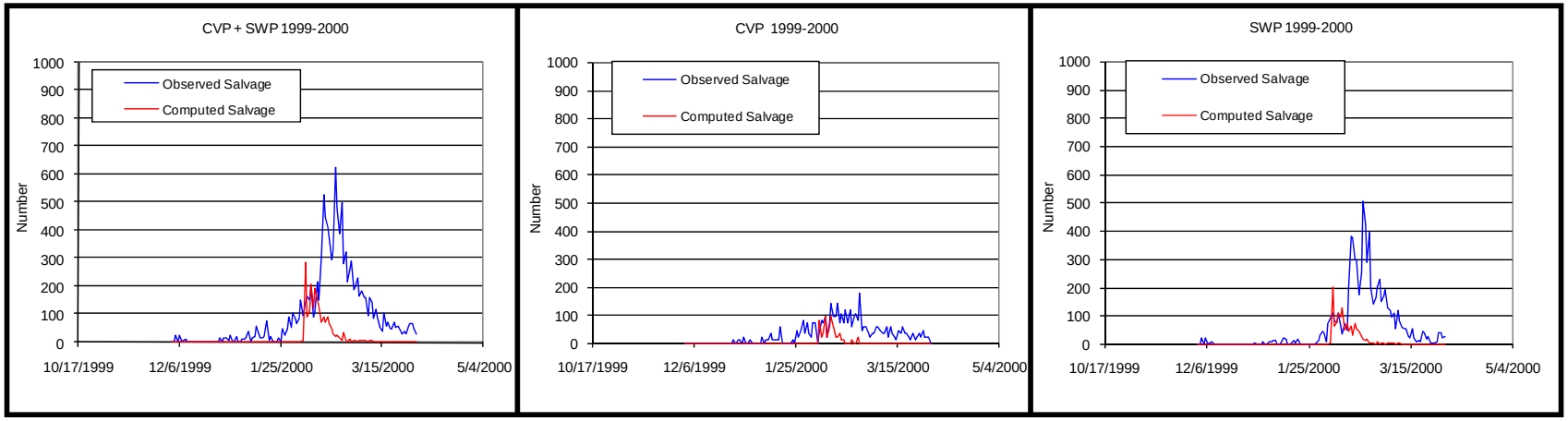

Figure 29 Observed and computed smelt salvage at the CVP and SWP exports during 1999-2000.

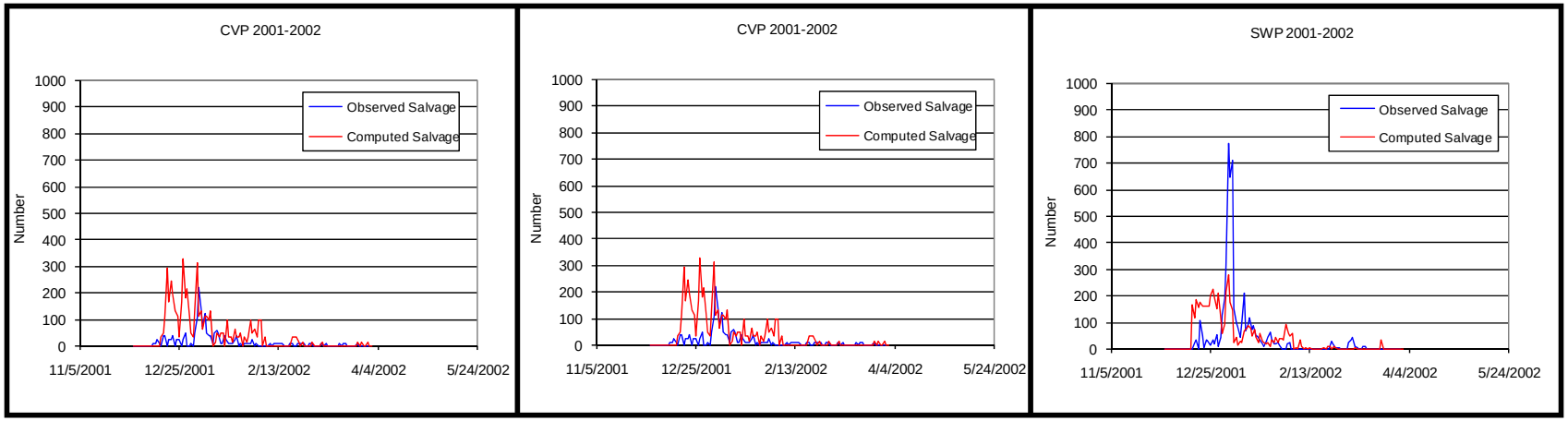

Figure 30 Observed and computed smelt salvage at the CVP and SWP exports during 2001-2002.

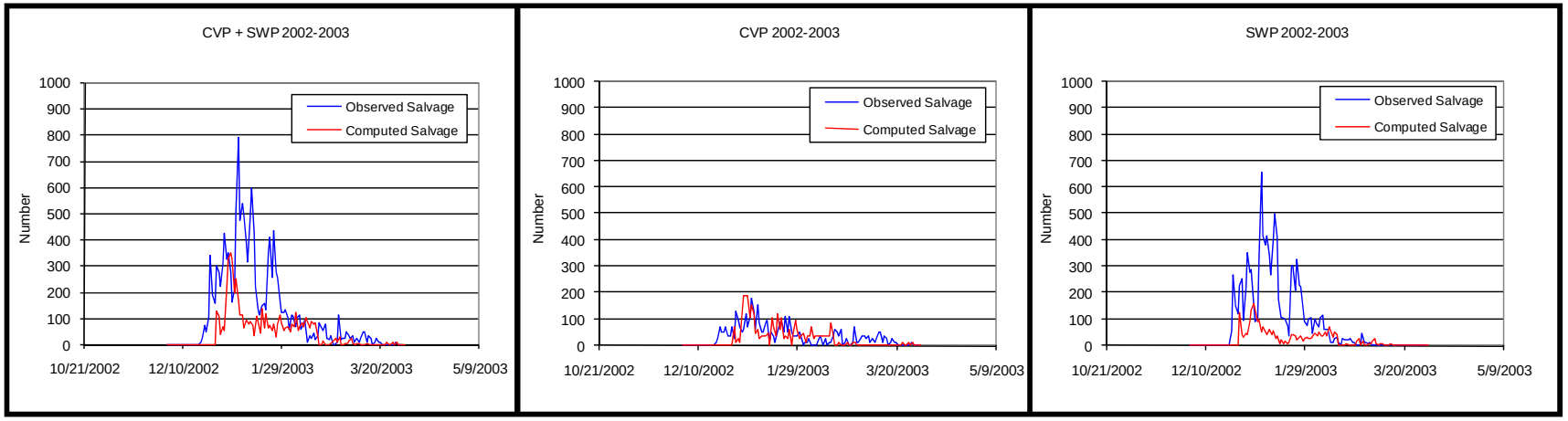

Figure 31 Observed and computed smelt salvage at the CVP and SWP exports during 2002-2003.

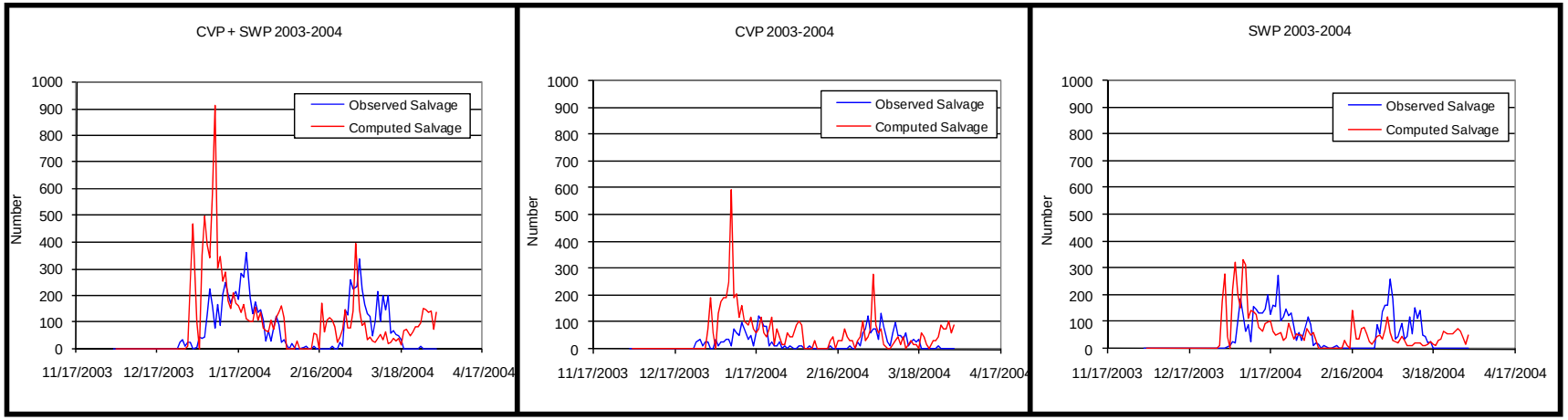

Figure 32 Observed and computed smelt salvage at the CVP and SWP exports during 2003-2004.

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 34 through Figure 40. 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 37). 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 39. 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 40). 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	--

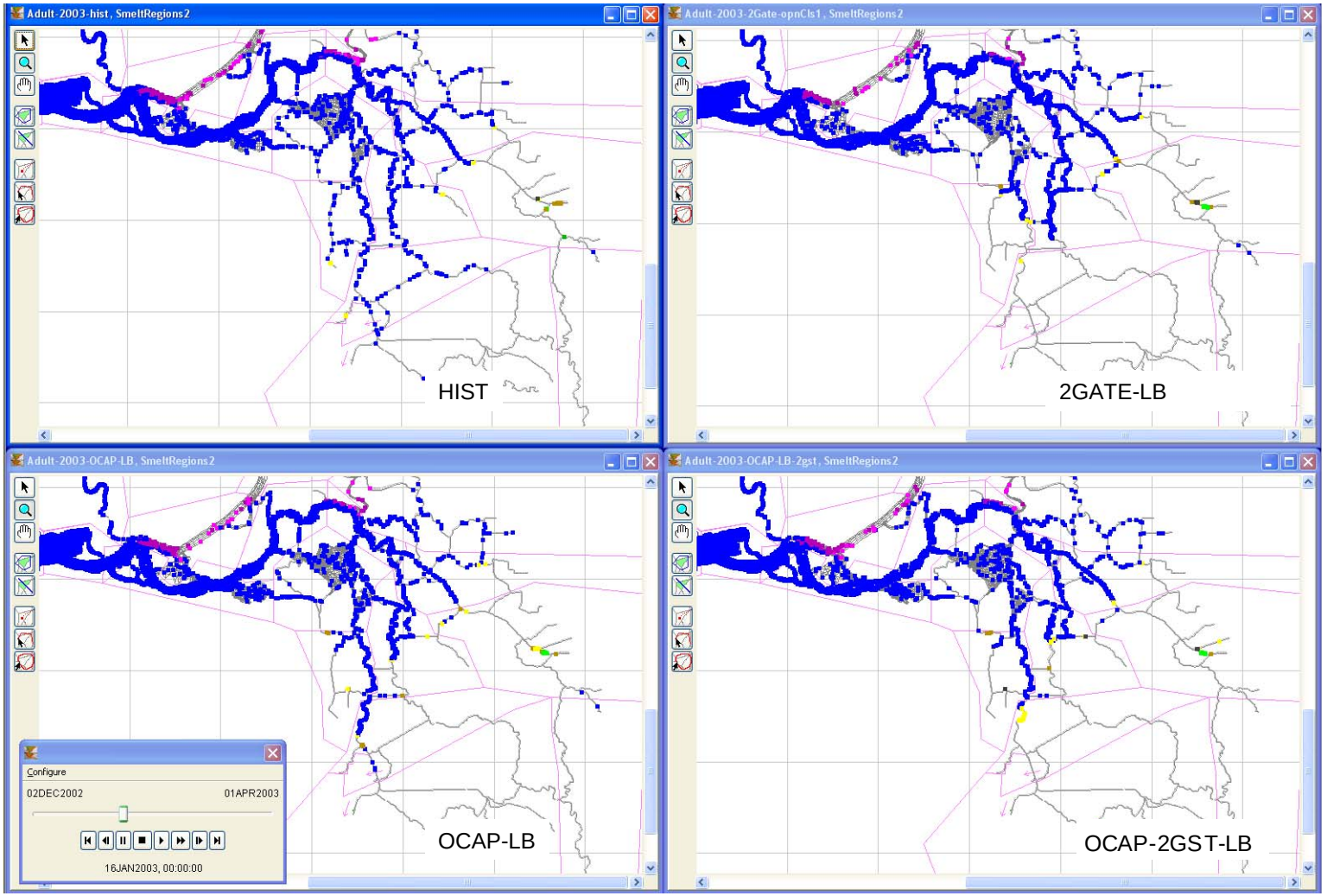

Figure 33 Adult Delta Smelt Particle Distributions for historical conditions, OCAP operations, 2-gate scenario, and OCAP operations with 2-gate start time (OCAP-2GST) on 16 Jan 2003 at 00:00.

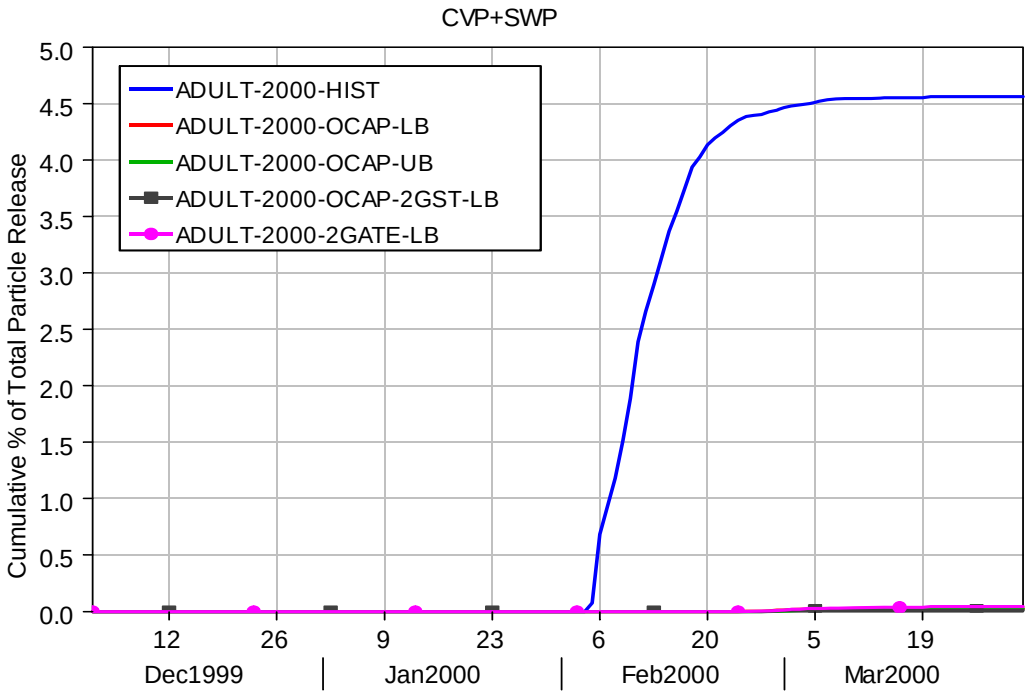

Figure 34 Cumulative entrainment as percent of total particles released at the CVP and SWP export locations, December 1999 through March 2000.

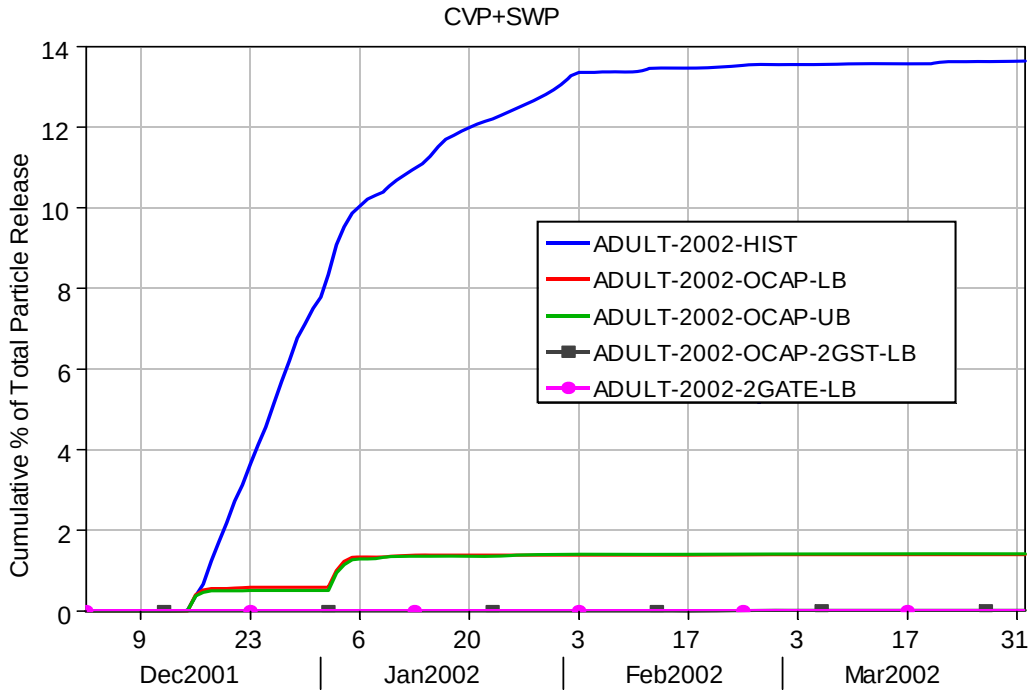

Figure 35 Cumulative entrainment as percent of total particles released at the CVP and SWP export locations, December 2001 through March 2002.

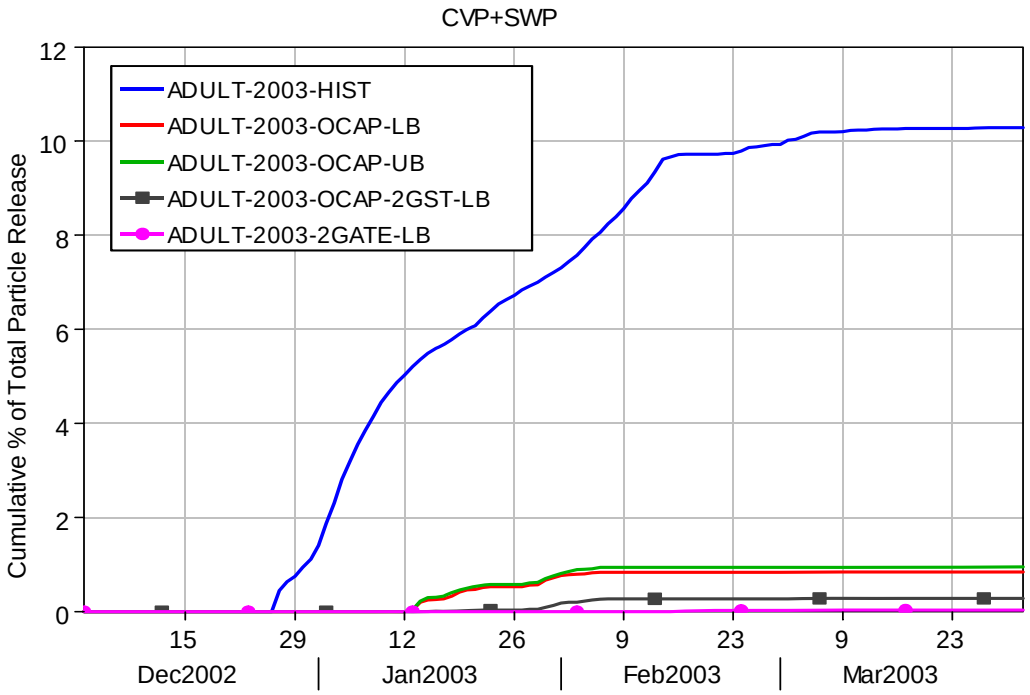

Figure 36 Cumulative entrainment as percent of total particles released at the CVP and SWP export locations, December 2002 through March 2003.

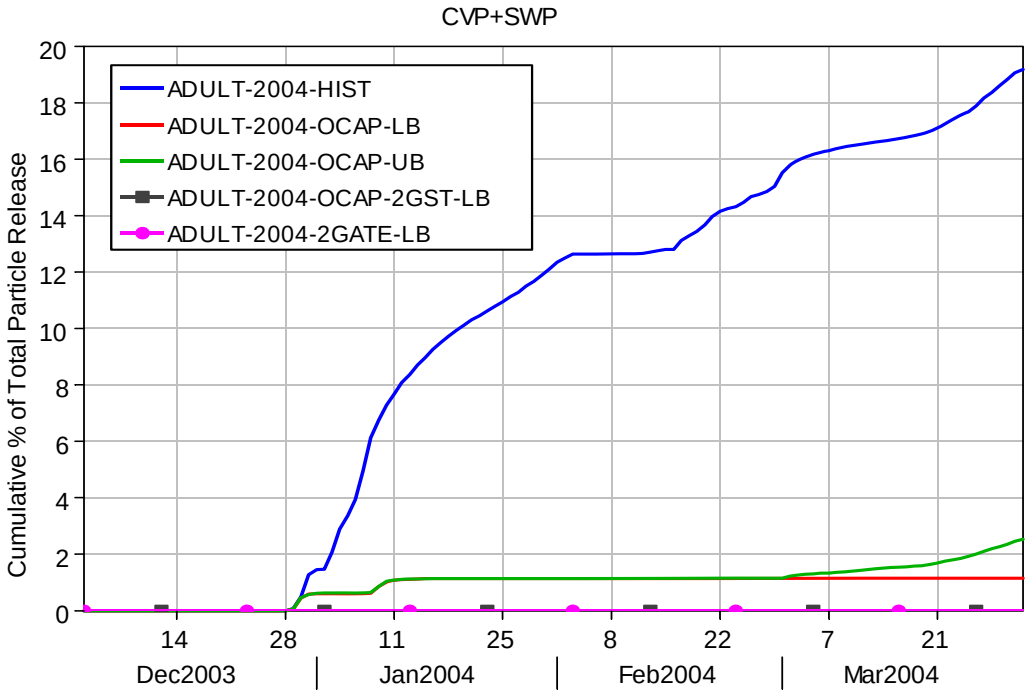

Figure 37 Cumulative entrainment as percent of total particles released at the CVP and SWP export locations, December 2003 through March 2004.

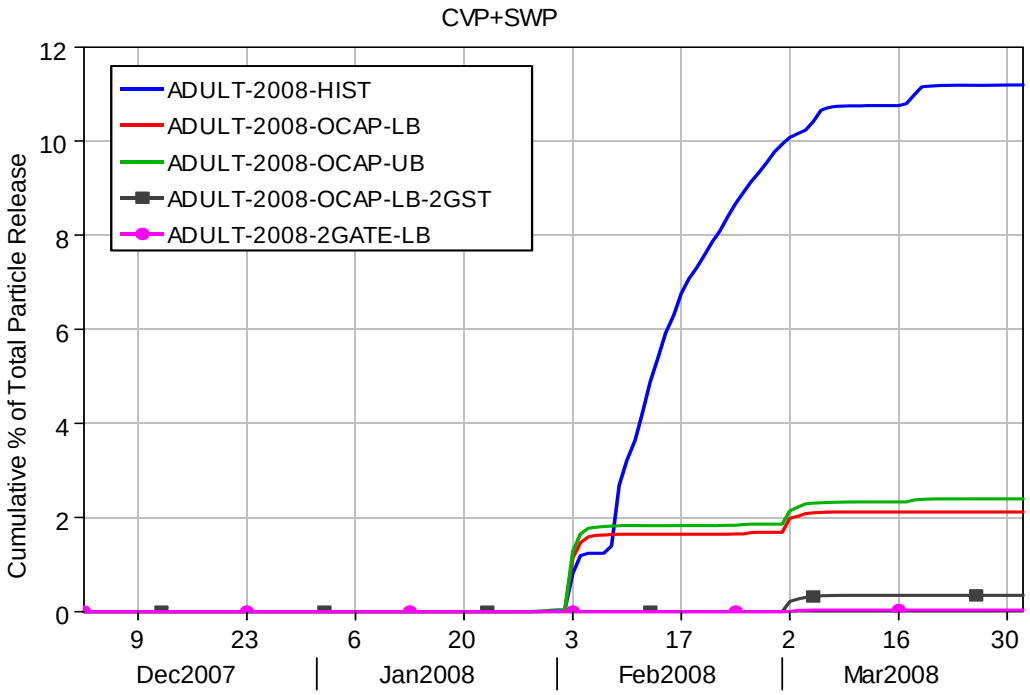

Figure 38 Cumulative entrainment as percent of total particles released at the CVP and SWP export locations, December 2007 through March 2008.

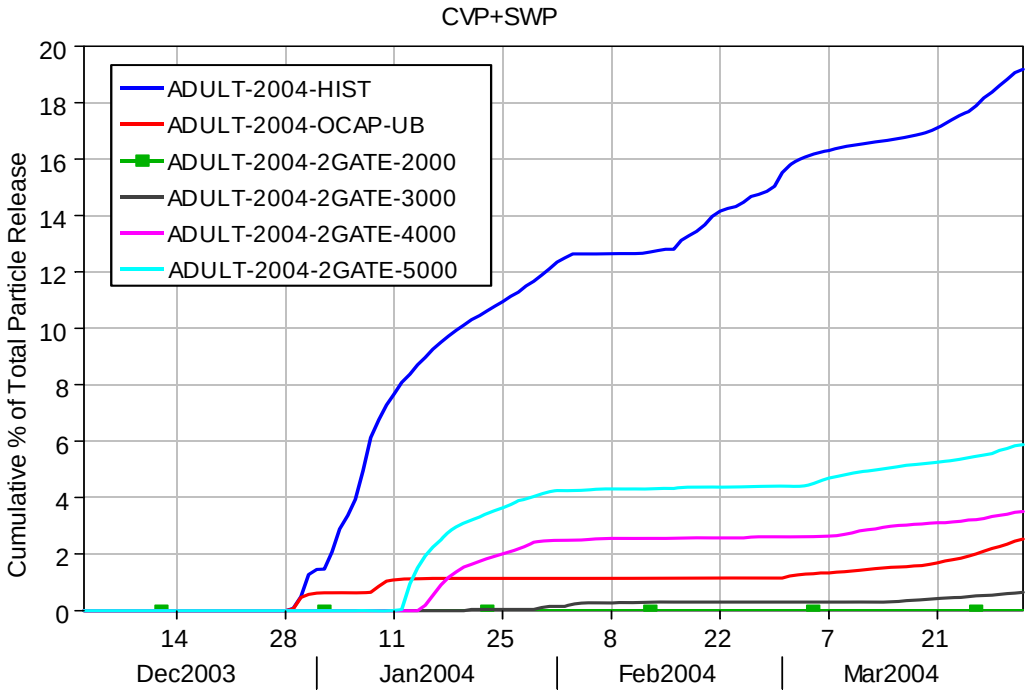

Figure 39 Cumulative entrainment as percent of total particles released at the CVP and SWP export locations, December 2003 through March 2004, with alternative OMR flow limits .

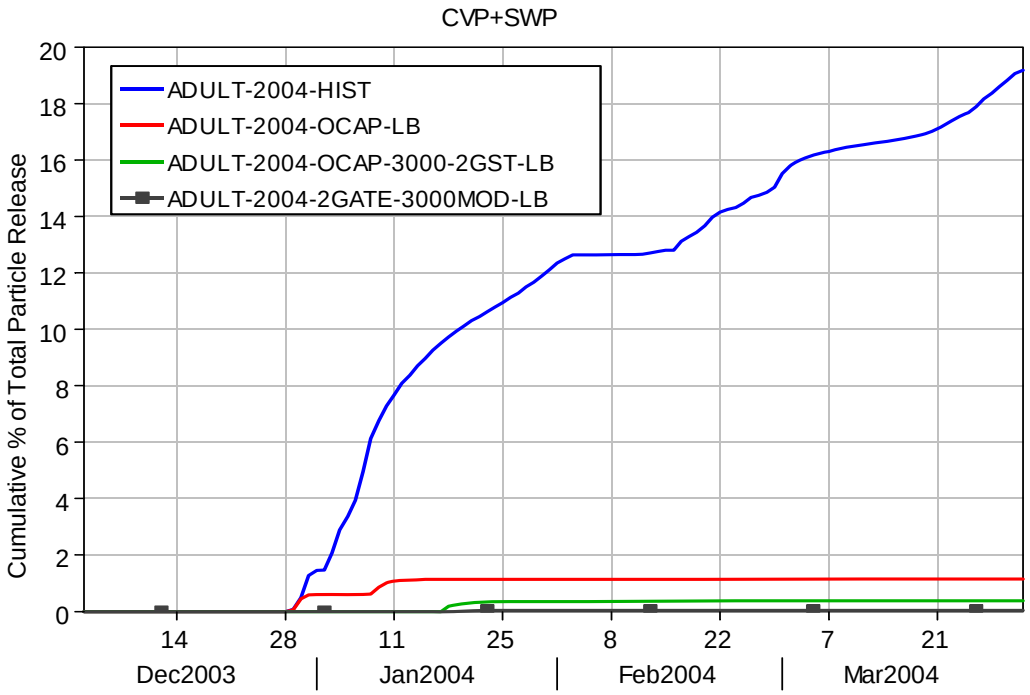

Figure 40 Cumulative entrainment as percent of total particles released at the CVP and SWP export locations, December 2003 through March 2004, with -3000 cfs OMR flows during RPA1 and lower bound flows during RPA2. For the 2-gate case, exports were reduced briefly near the end of January to maintain positive Qwest at San Andreas Landing.

Larval/Juvenile Smelt Simulations

The original goal of this analysis was to objectively estimate the delta smelt hatching distribution that is, by some metric, most consistent with available observations of delta smelt distribution and salvage, and then perform alternative simulations considering the OCAP BO and 2-Gate operations based on historically derived hatching distributions. Historic simulations use the RMA Bay-Delta Model and RMATRK for passive particle tracking. A post-processing tuning analysis was developed to estimate regional hatching rates which were 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).

Although development of the historic hatching distributions was completed, the decision was made not to proceed with alternative analysis for larval/juvenile delta smelt at this time due to uncertainty in the analysis process leading to the historic hatching distributions and current inability to link changes in adult distributions (due to hypothetical alternative operations) with changes in hatching distributions. The new objective for future efforts is to investigate better approaches for estimating hatching distributions, hopefully with linkage to the adult distributions.

The following sections describe the current state of development of the historic hatching distributions and comparison with survey observations. For alternative operations, un-scaled percent entrainment by region, which uses passive particle tracking results without consideration of hatching distribution or mortality, is analyzed for 2000, 2003 and 2004. While this analysis does not consider the variation of larval/juvenile density between regions, which would be required to assess the population impacts of 2-Gate operation, comparison of un-scaled percent entrainment does provide insight as to the zone of influence of the 2-Gate project operation and how entrainment is expected to vary from region to region.

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 41) 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

(fishm^{-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 41) 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.

Hatching distributions are not linked to earlier adult distributions. Therefore, when simulated adult distributions change due to alternative operation scenarios, the modified distribution of adults does not affect the hatching distributions.

Because of the significant limitations in estimating hatching distributions, and the inability to link changes in adult distributions with changes in hatching distributions, alternative analysis of larval/juvenile delta smelt based on hatching distributions will not be pursued at this time. The analysis of alternatives will be based only on un-scaled percent entrainment by region. This is itself a limitation because the larval/juvenile density in each region is not considered at this time.

Results of the 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 2000, 2003 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, 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

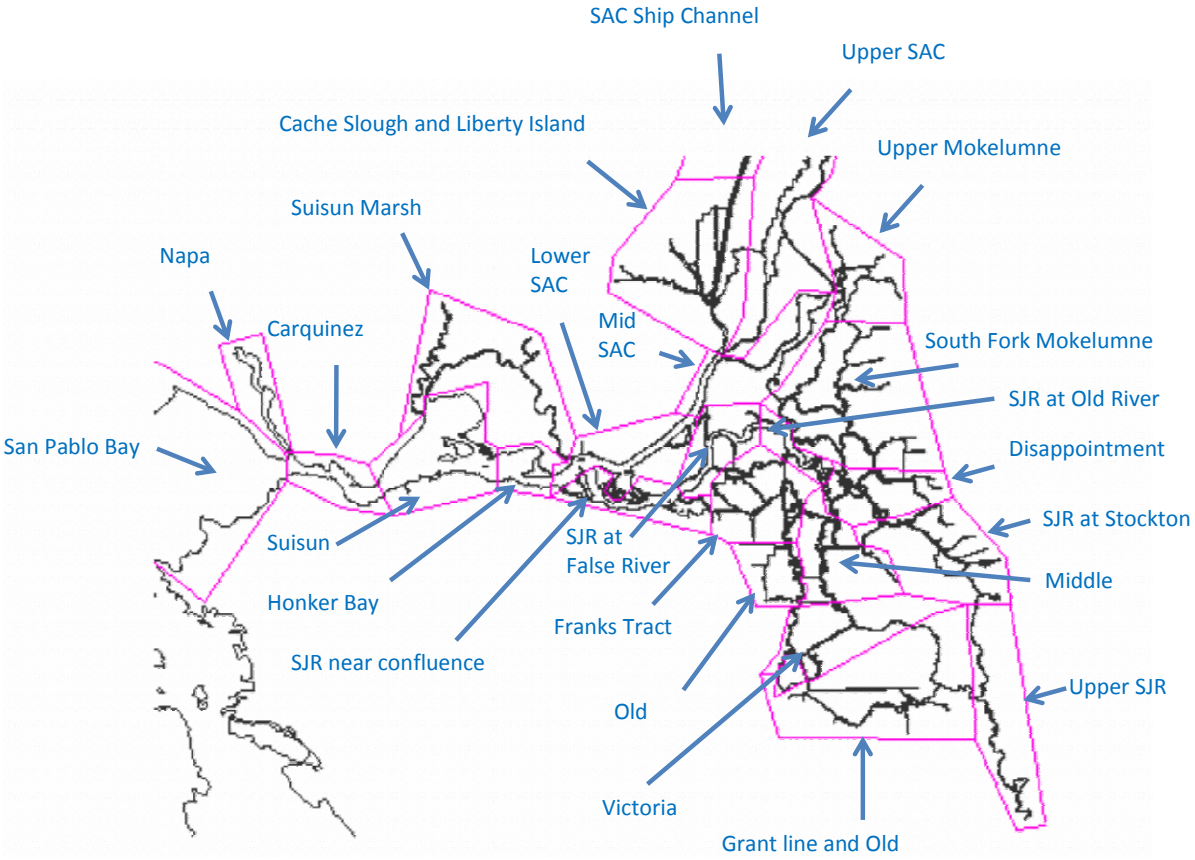

Figure 41 Source regions.

Discussion of Results for 2000

Historical

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 43. 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 45. 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 46. This figure suggests that the average distribution through the simulation period is predicted quite well. In Figure 44, 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 47. 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.

Alternatives Analysis

In 2000, and other simulation periods, the results can be understood largely in terms of effects on the Old and Middle River flow corridors. While the reduced flows in OCAP reduce the flows through these corridors, the gate operations make 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 48 and Figure 49.

Both the OCAP flow reductions and the gate operations make flows on Old River less negative, as shown in Figure 49. Therefore a lower percentage of 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 percent entrainment as a result of OCAP flow limitations. The predicted percent entrainment is decreased more substantially as a result of the optimized gate operations. 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 percent of particles from each source region that are entrained is shown in Figure 50. 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 percent entrainment due to less negative flows on Old River, resulting in reduced percent entrainment from western and central Delta sources, it is likely that the gate operations decrease percent 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. Furthermore, if recirculated particles are entrained, they will be older, leading to a lower predicted percent 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.

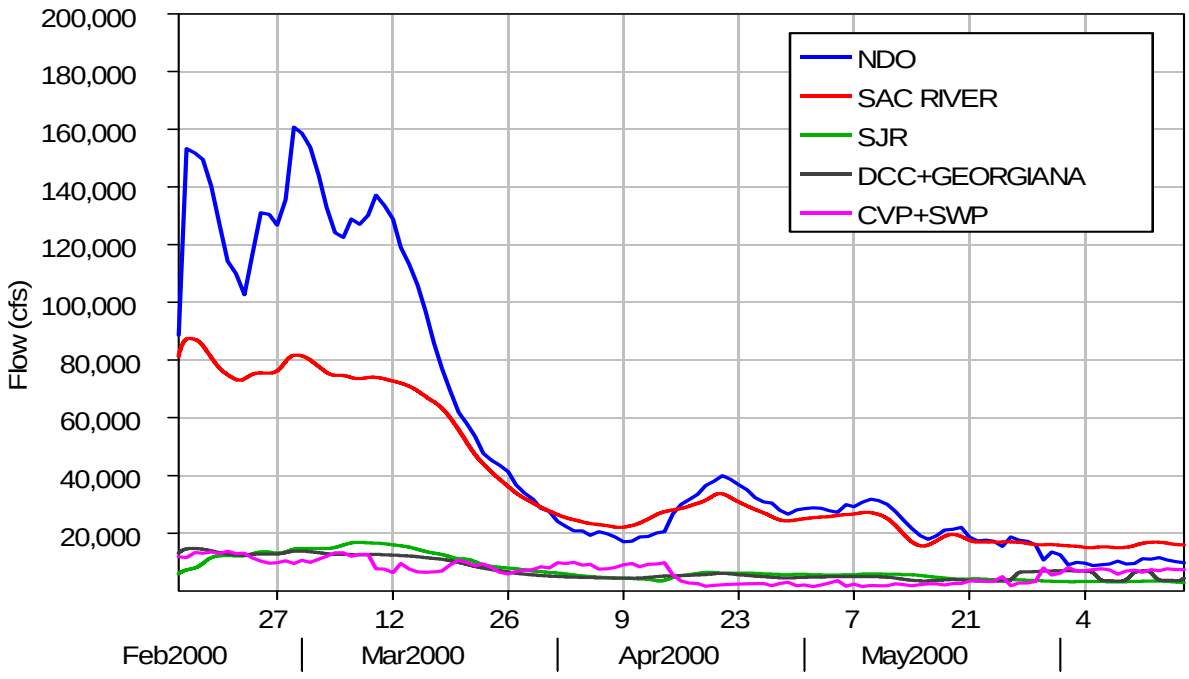

Figure 42 Net flows from the 2000 Historical simulation.

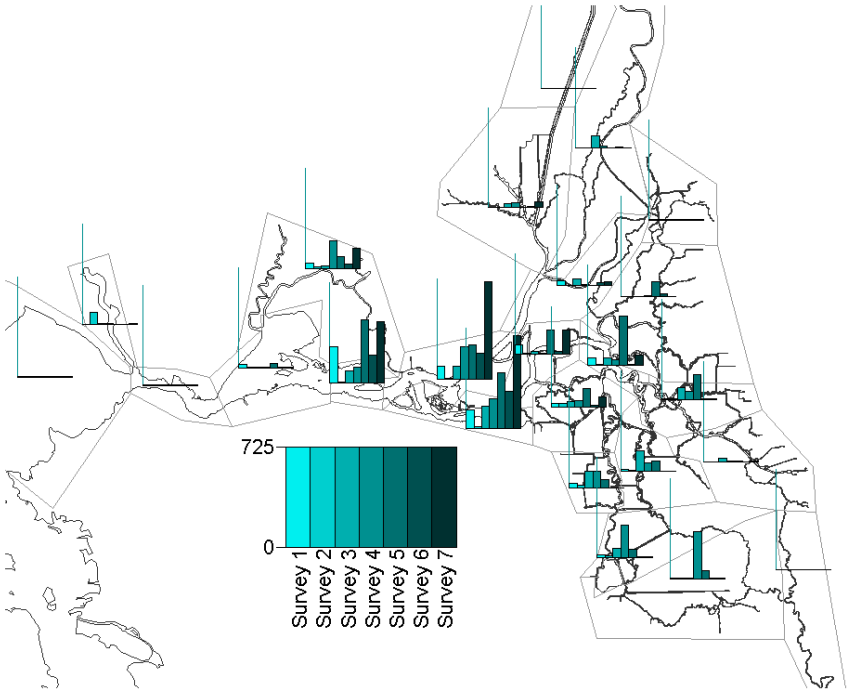

Figure 43 Regional Densities estimated from 20 mm Trawl Surveys, 2000.

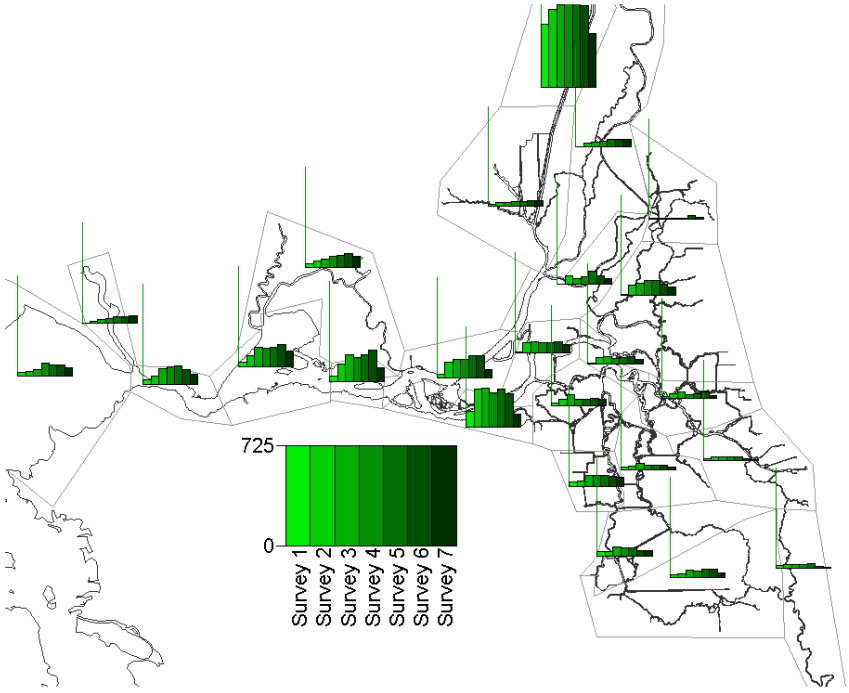

Figure 44 Regional Densities estimated by the Particle Model on survey dates, 2000.

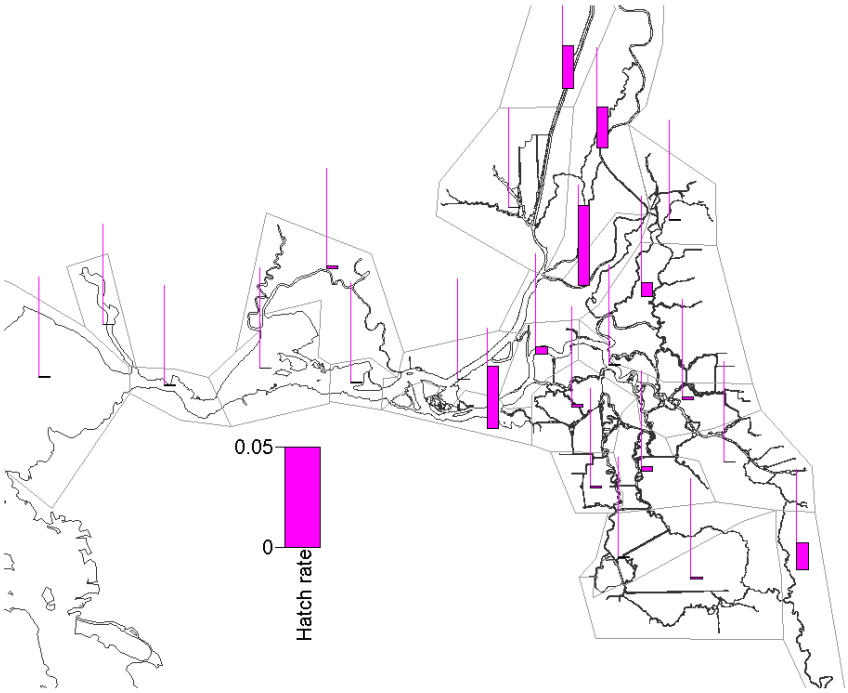

Figure 45 Tuned Regional Hatching Rates, 2000.

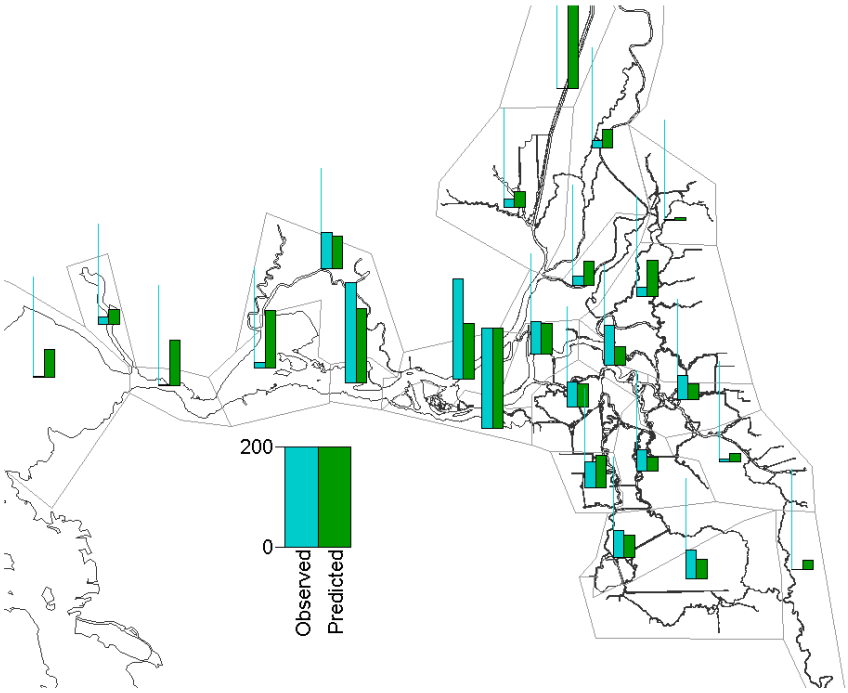

Figure 46 Comparison of Regional Densities estimated from 20 mm Trawl Surveys and Predicted by Particle Model averaged over all surveys, 2000.

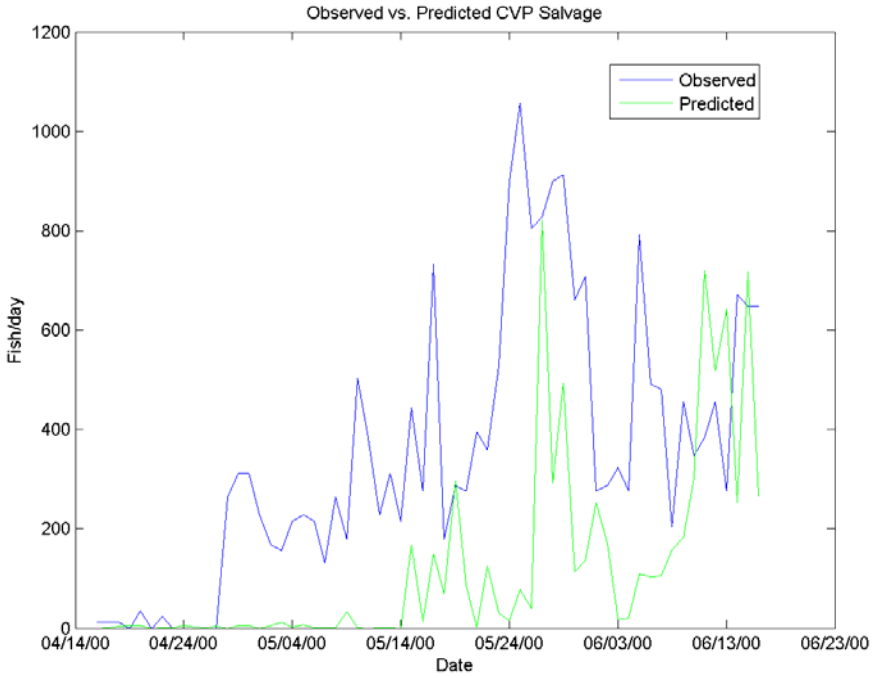

Figure 47 Time-series of Observed CVP Salvage and Salvage estimated from Particle Entrainment, 2000.

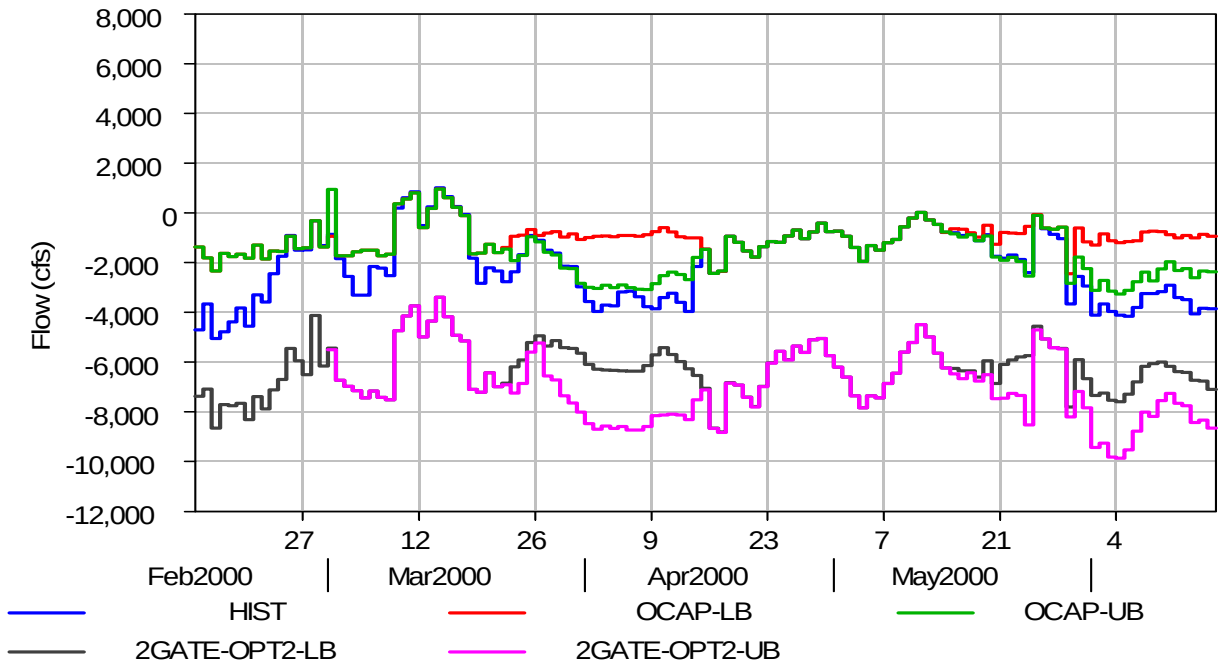

Figure 48 Daily average flows for February – June 2000 at RMID015.

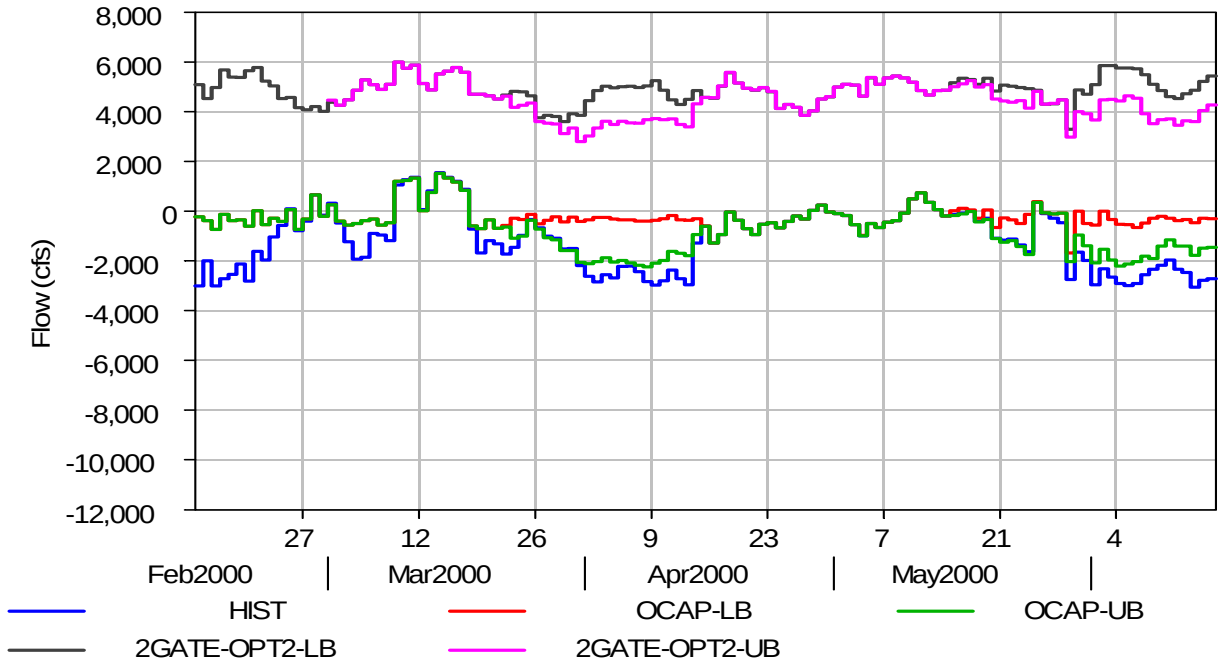

Figure 49 Daily average flows for February – June 2000 at ROLD024.

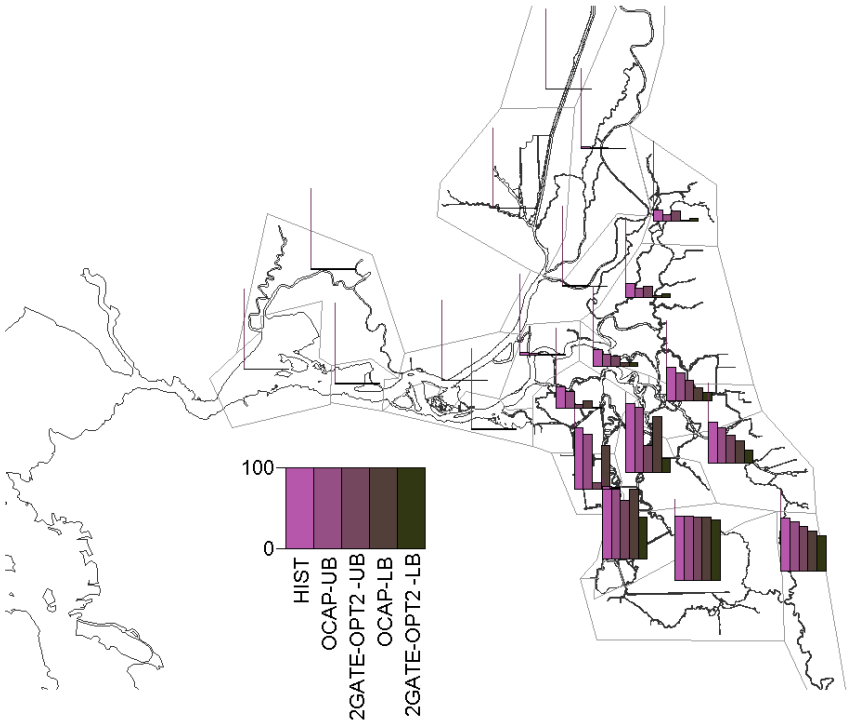

Figure 50 Percentage particles entrained at CVP+SWP from each region during the period February 15 - June 15, 2000.

Discussion of Results for 2003

Historical

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 52. 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 54. 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 55. This figure suggests that the average distribution through the simulation period is predicted quite well. In Figure 53, 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 56. 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.

Alternatives Analysis

In 2003 and other simulation periods, the results can be understood largely in terms of effects on the Old and Middle River flow corridors. While the reduced flows in OCAP reduce the flows through these corridors, the gate operations make Middle River flows more negative and Old River flows less negative, as shown in Figure 57 and Figure 58.

Both the OCAP flow reductions and the gate operations make flows on the Old River less negative, as shown in Figure 58. Therefore a lower percentage of particles/fish are entrained from Franks Tract and the San Joaquin near Old River under these scenarios than the historical scenarios.

The percent of particles from each source region that are entrained is shown in Figure 59. Percent 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.

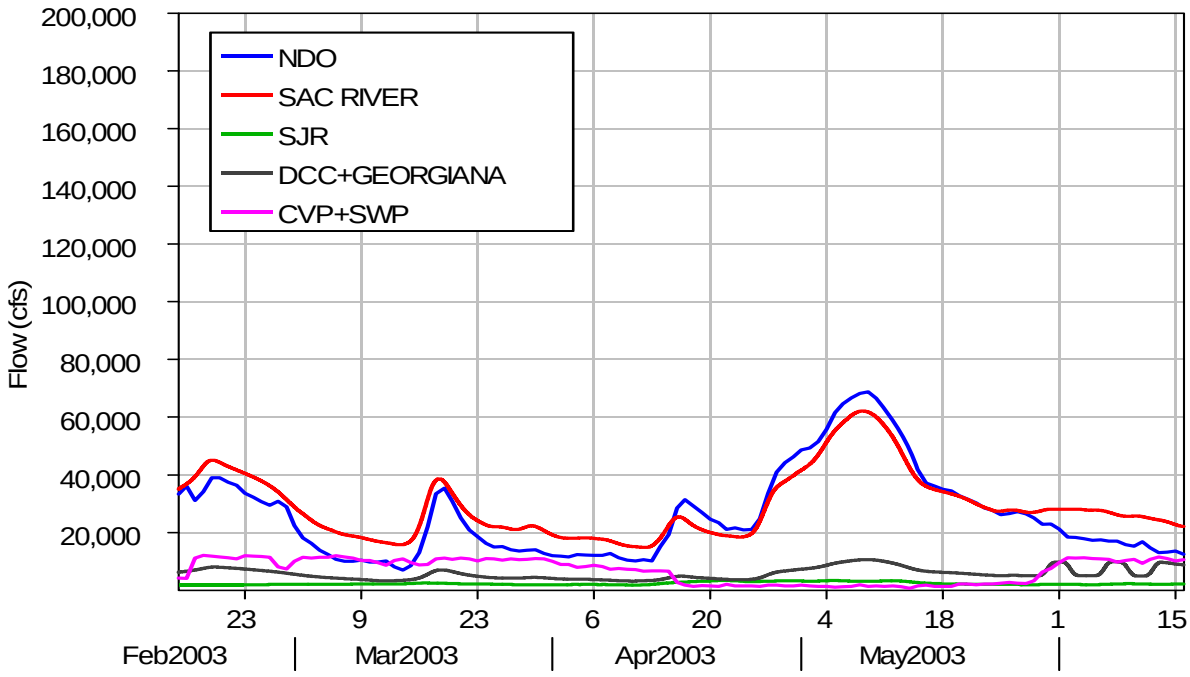

Figure 51 Net flows from the 2003 Historical simulation.

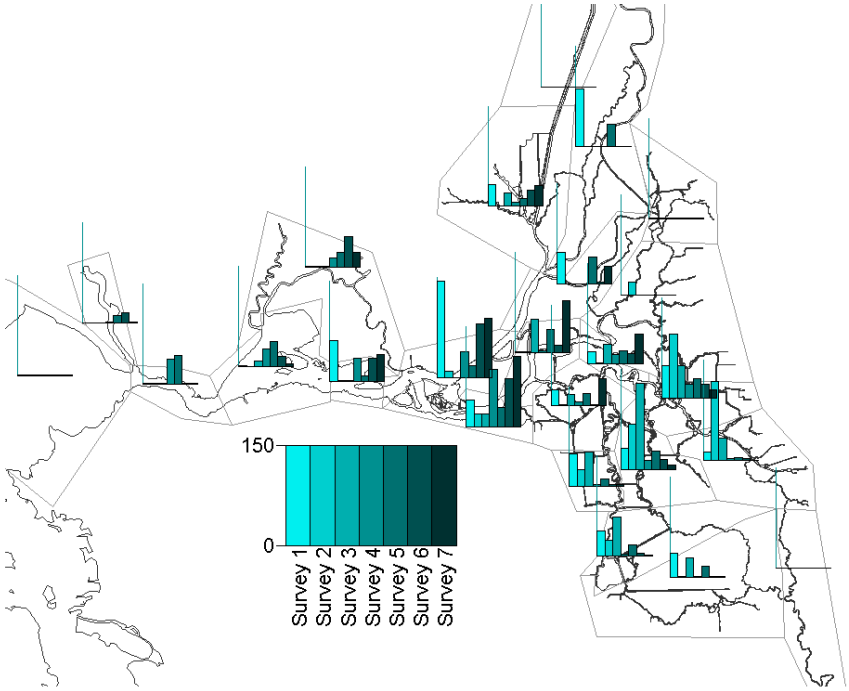

Figure 52 Regional Densities estimated from 20 mm Trawl Surveys, 2003.

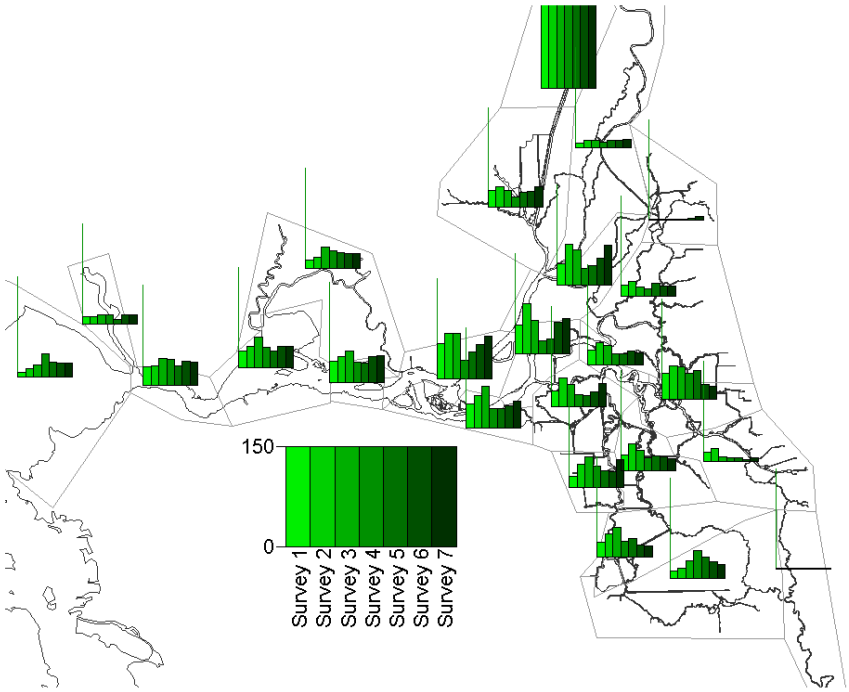

Figure 53 Regional Densities estimated by the Particle Model on survey dates, 2003.

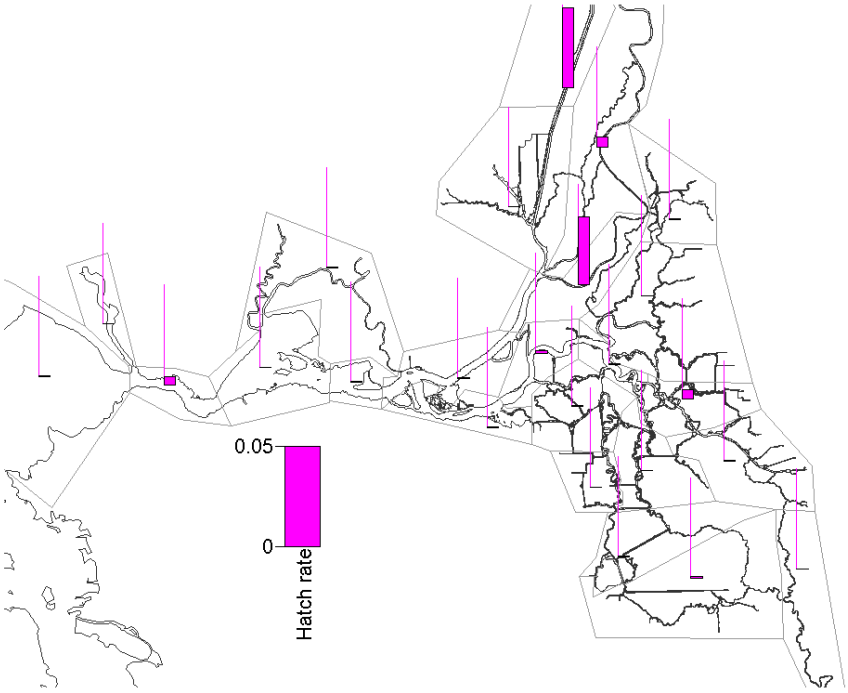

Figure 54 Tuned Regional Hatching Rates, 2003.

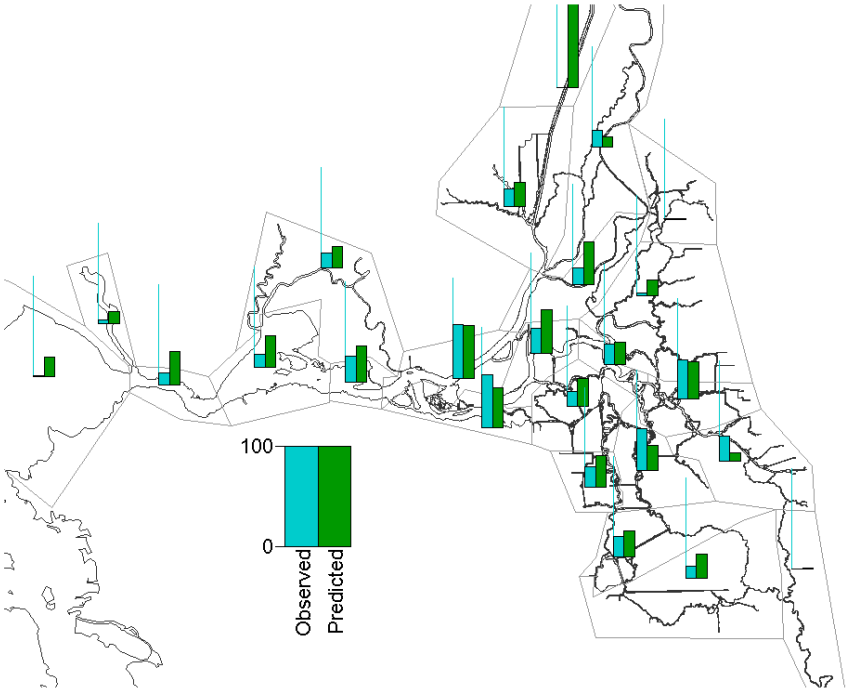

Figure 55 Comparison of Regional Densities estimated from 20 mm Trawl Surveys and Predicted by Particle Model averaged over all surveys, 2003.

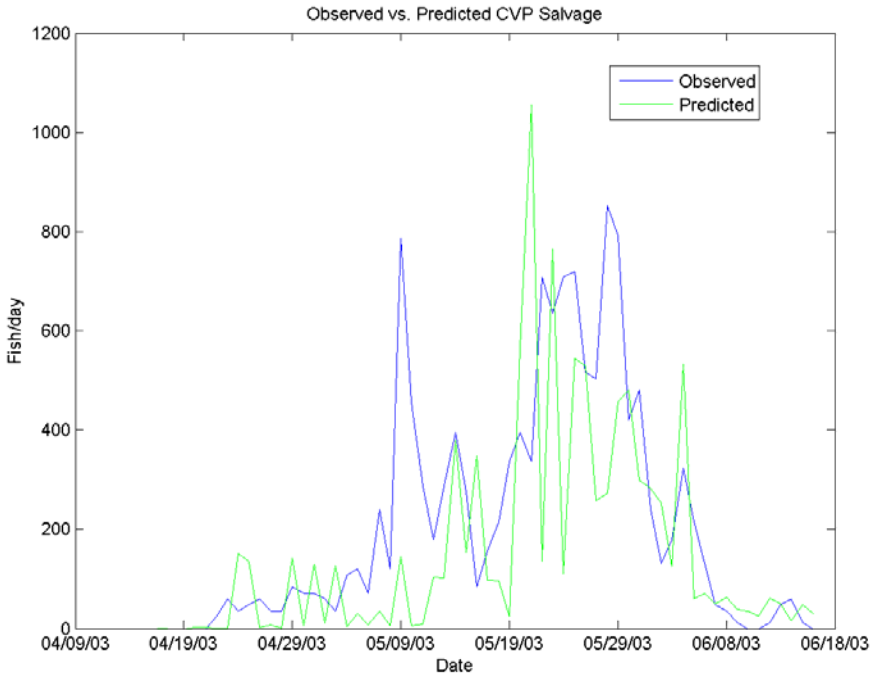

Figure 56 Time-series of Observed CVP Salvage and Salvage estimated from Particle Entrainment, 2003.

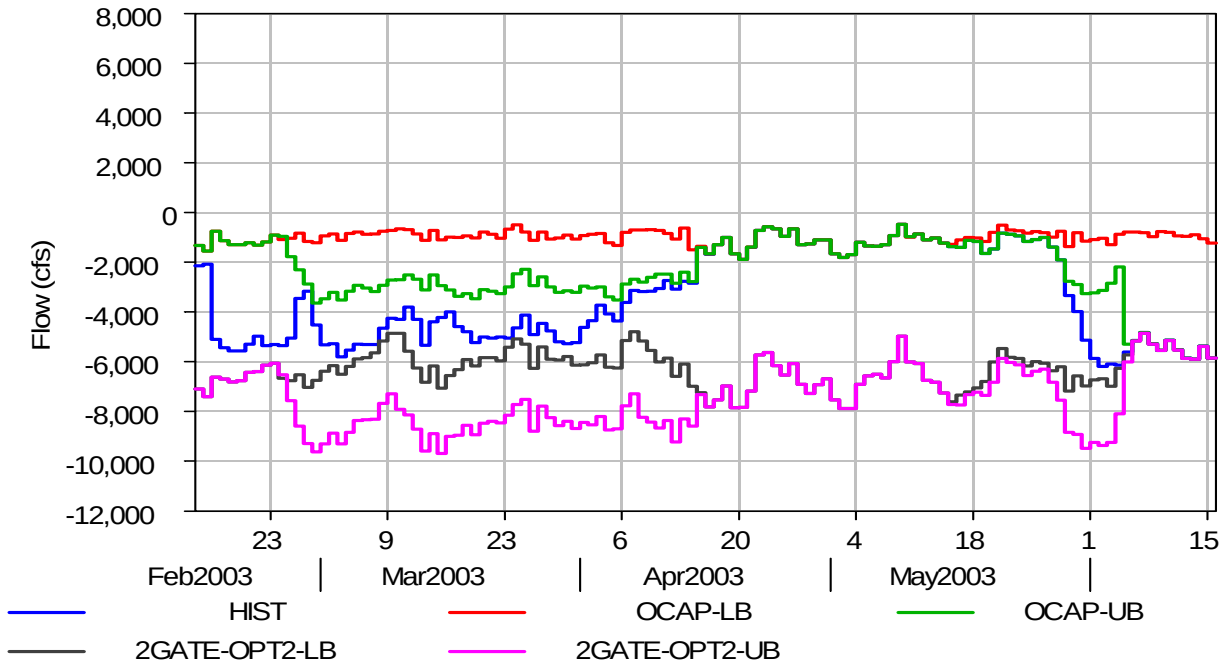

Figure 57 Daily average flows for February – June 2003 at RMID015.

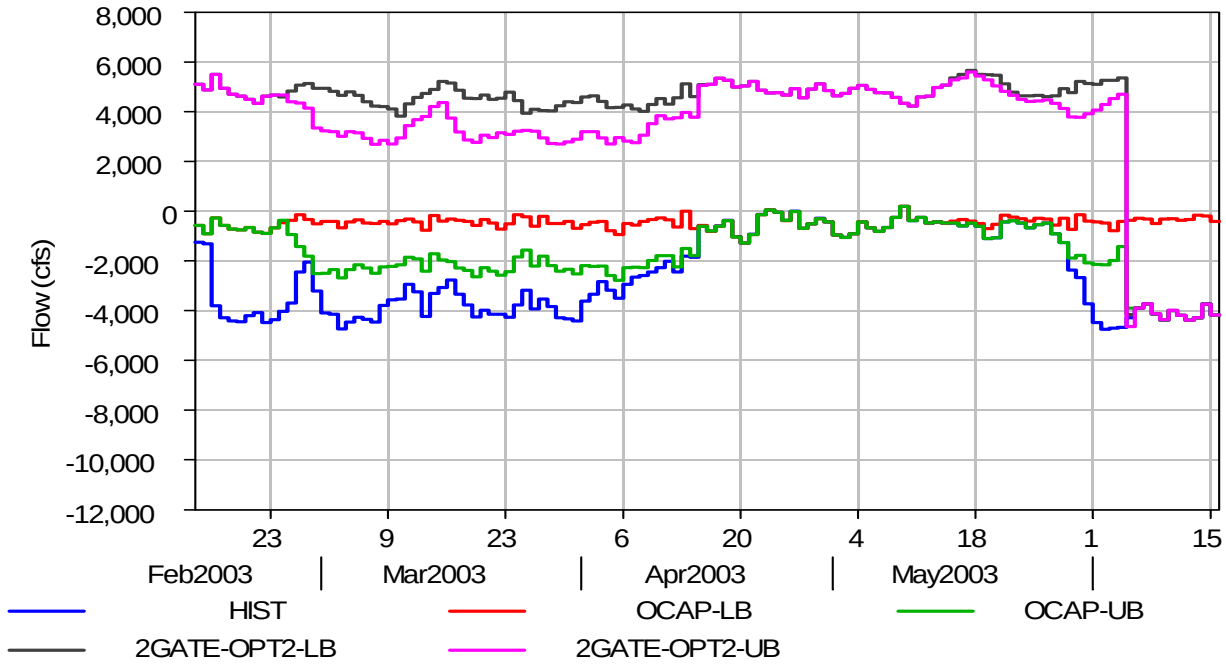

Figure 58 Daily average flows for February – June 2003 at ROLD024.

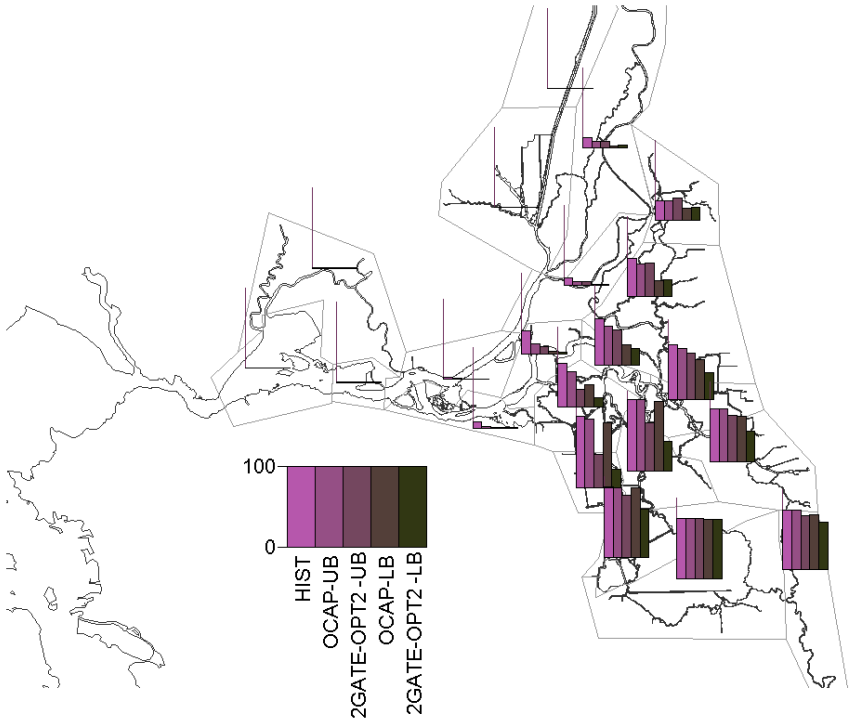

Figure 59 Percentage particles entrained at CVP+SWP from each region during the period February 15 - June 15, 2003.

Discussion of Results for 2004

Historical

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 61. 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 63. 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 64. 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 62, 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 65. 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.

Alternatives Analysis

In 2004 and other simulation periods, the results can be understood largely in terms of effects on the Old and Middle River flow corridors. While the reduced flows in OCAP reduce the flows through these corridors, the gate operations make Middle River flows more negative and Old River flows less negative (see Figure 66 and Figure 67).

Both the OCAP flow reductions and the gate operations make flows on the Old River less negative (Figure 67). Therefore a lower percentage of 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 percent entrainment as a result of OCAP flow limitations. The predicted percent entrainment is decreased further as a result of the optimized gate operations. 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. In the Grant Line and Old region, the net effect of the 2-gate operations is increased percent entrainment.

The percent of particles from each source region that is entrained is shown in Figure 68. 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 79, 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%. Note that this regional average does not include the "Upper Mokelumne" or "Upper SAC" regions, where the 2-gate operations result in increased entrainment relative to OCAP flow restrictions alone. It is essential to recognize that the importance of decreasing or increasing entrainment in a given region depends on the hatching that occurs in that region.

Time series of "unscaled" percent cumulative entrainment from for other regions are shown in Figure 69 through Figure 78.

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. 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.

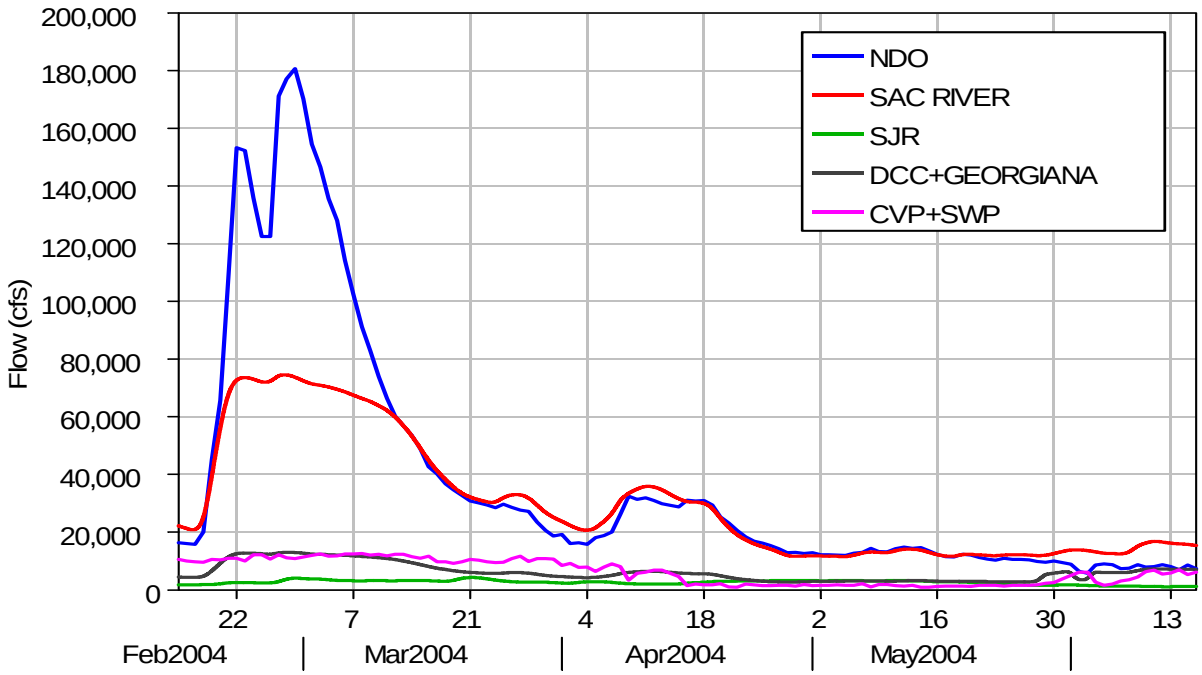

Figure 60 Net flows from the 2004 Historical simulation.

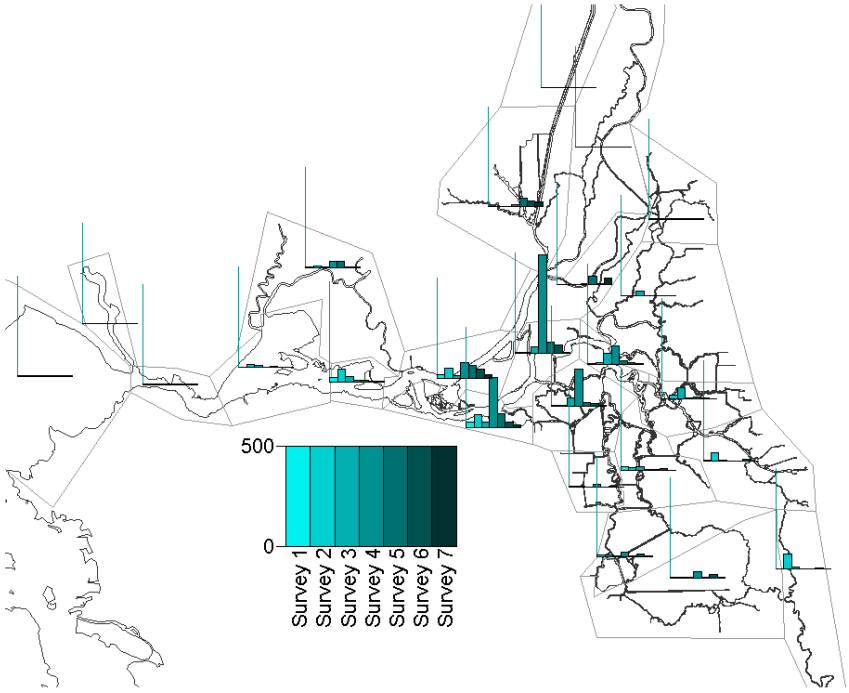

Figure 61 Regional Densities estimated from 20 mm Trawl Surveys, 2004.

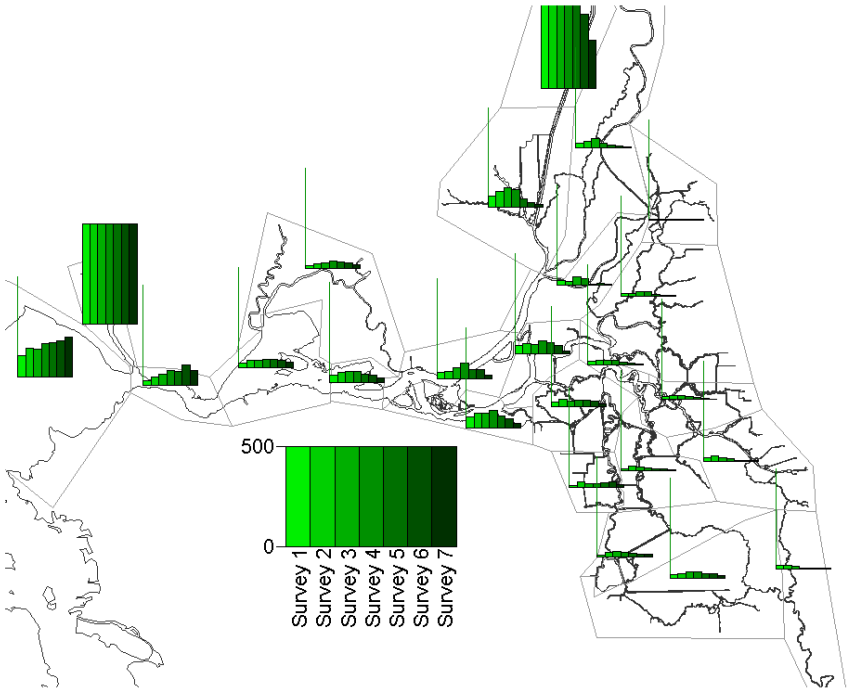

Figure 62 Regional Densities estimated by the Particle Model on survey dates, 2004.

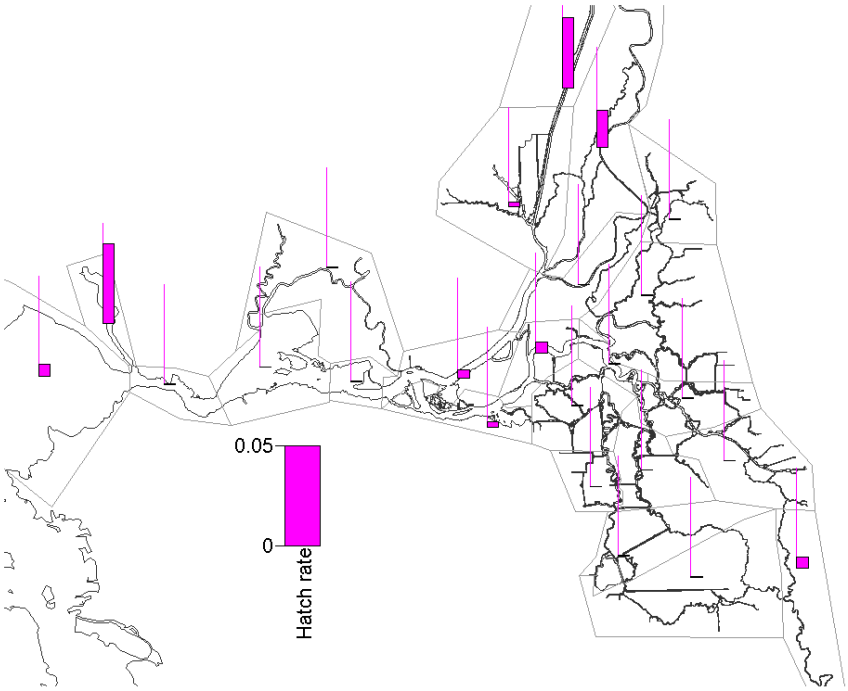

Figure 63 Tuned Regional Hatching Rates, 2004.

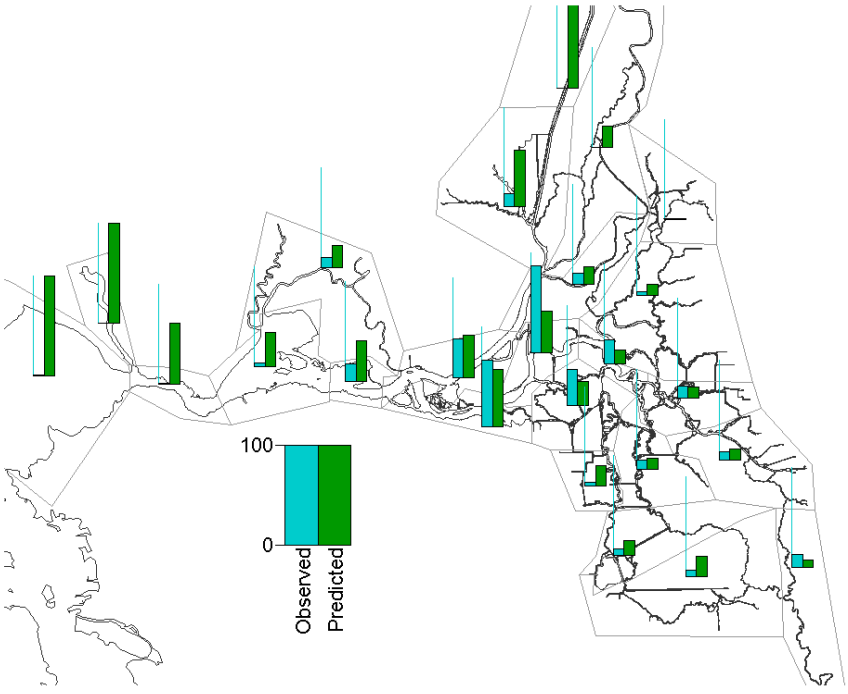

Figure 64 Comparison of Regional Densities estimated from 20 mm Trawl Surveys and Predicted by Particle Model averaged over all surveys, 2004.

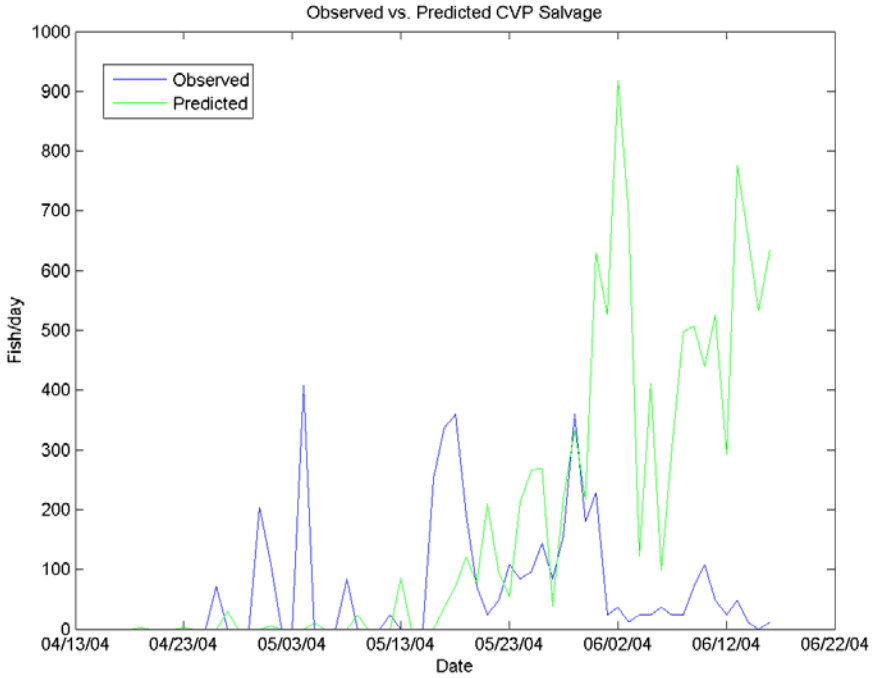

Figure 65 Time-series of Delta-wide Population estimated from 20 mm Trawl Surveys and from Particle Model, 2004.

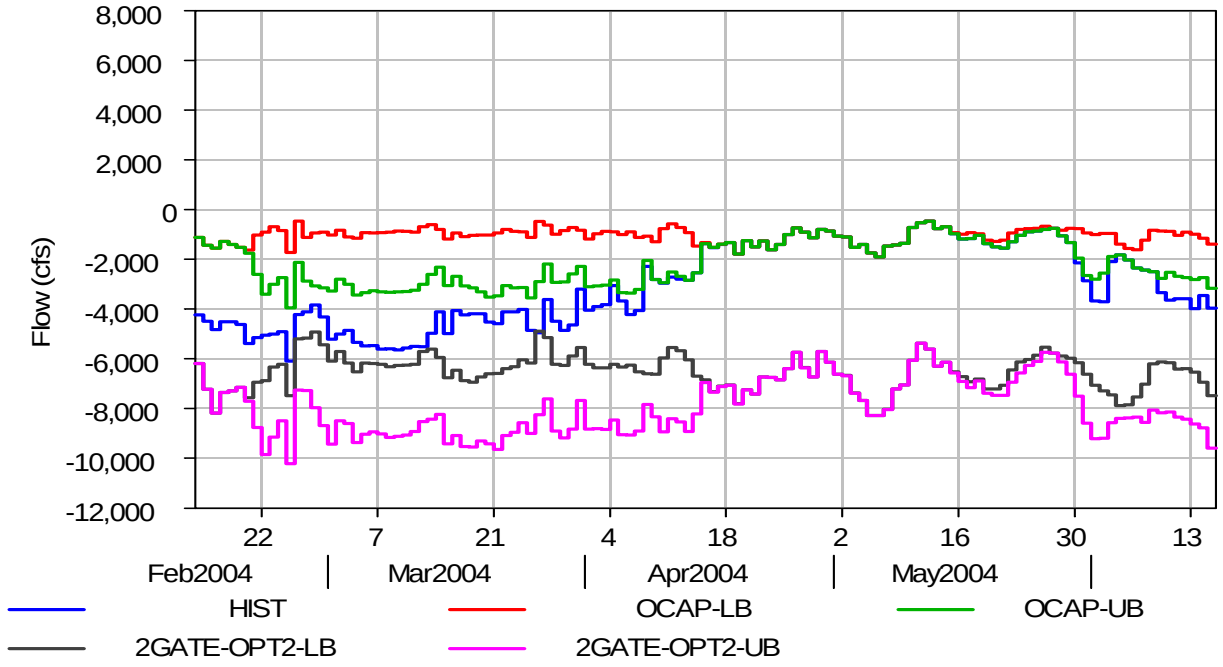

Figure 66 Daily average flows for February – June 2004 at RMID015.

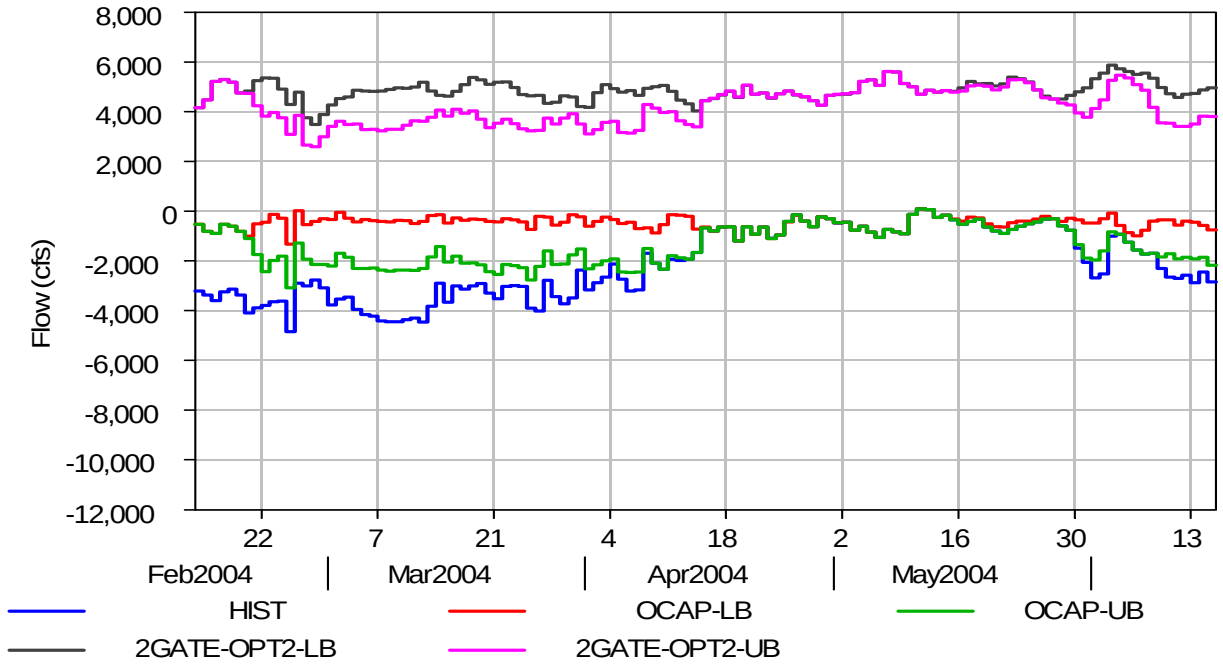

Figure 67 Daily average flows for February – June 2004 at ROLD024.

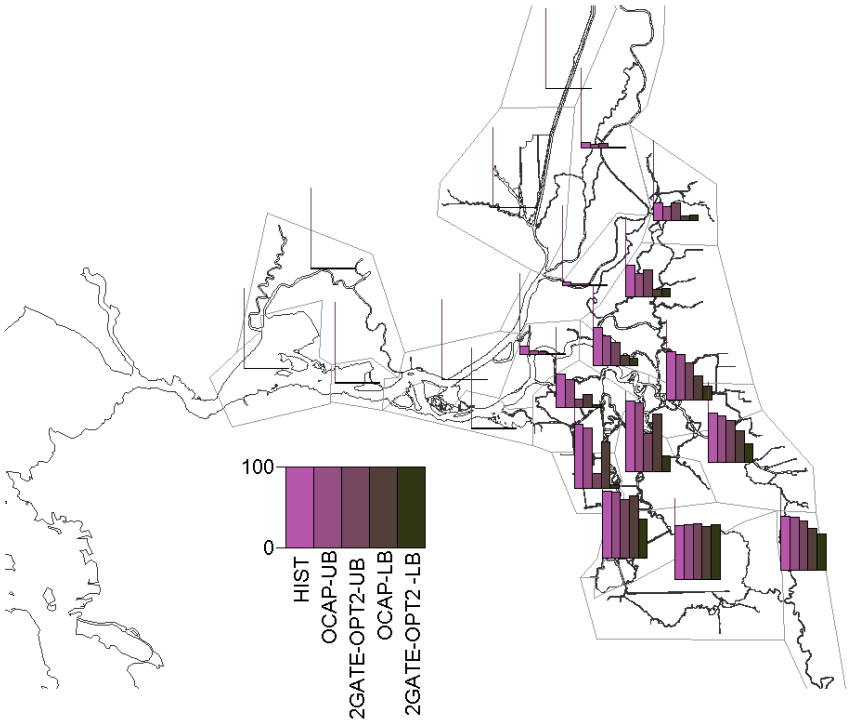

Figure 68 Percentage particles entrained at CVP+SWP from each region during the period February 15 - June 15, 2004.

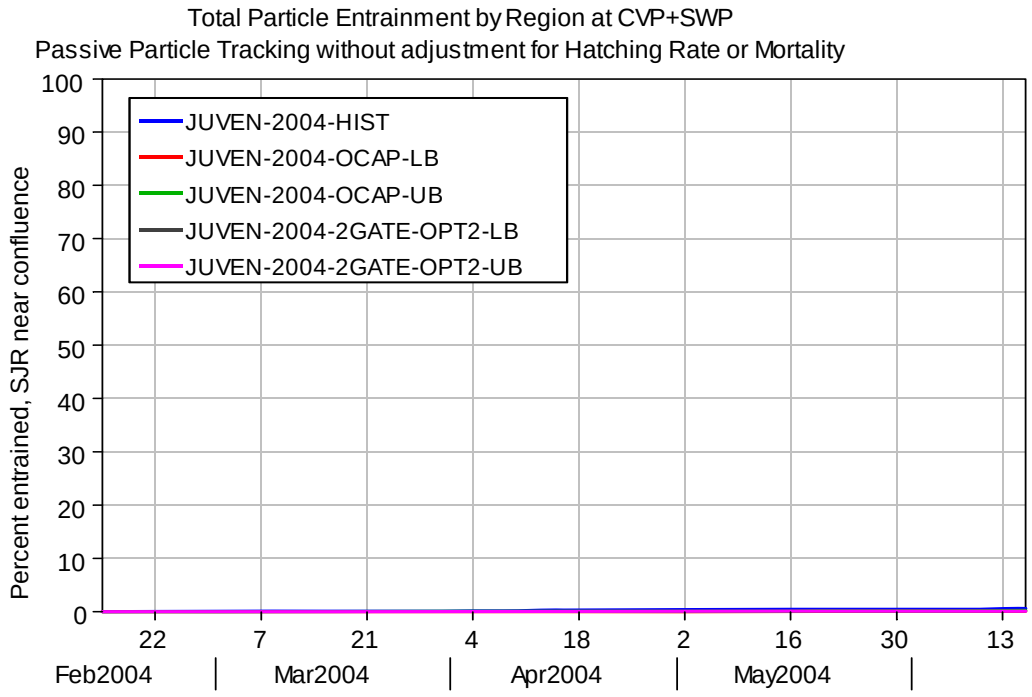

Figure 69 Percent particles entrained at the CVP+SWP originating from the region "SJR near confluence".

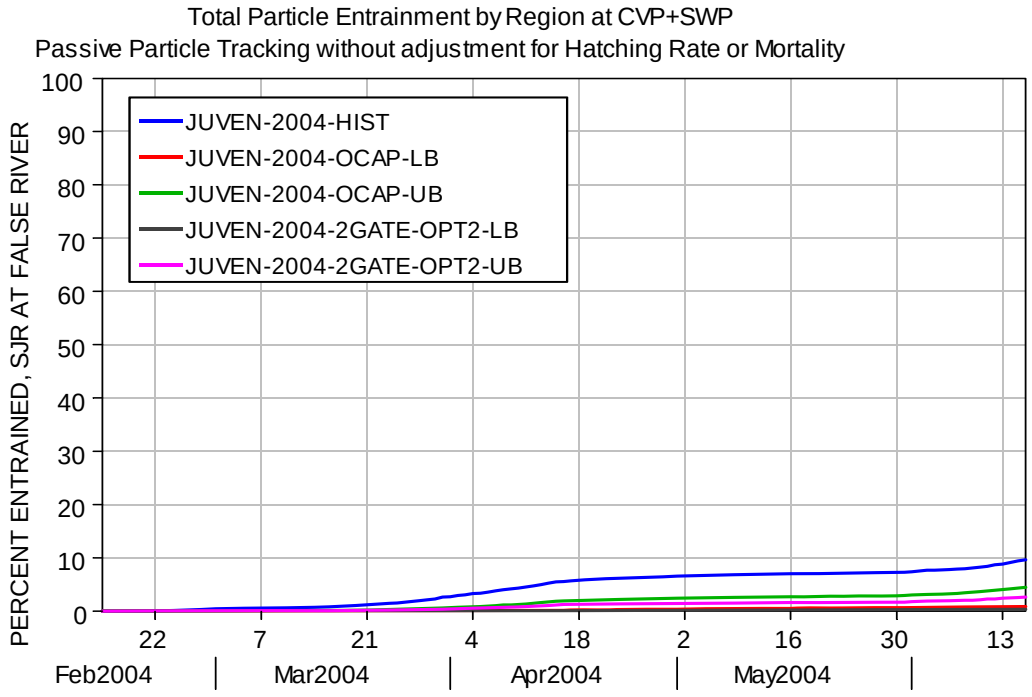

Figure 70 Percent particles entrained at the CVP+SWP originating from the region "SJR at False River".

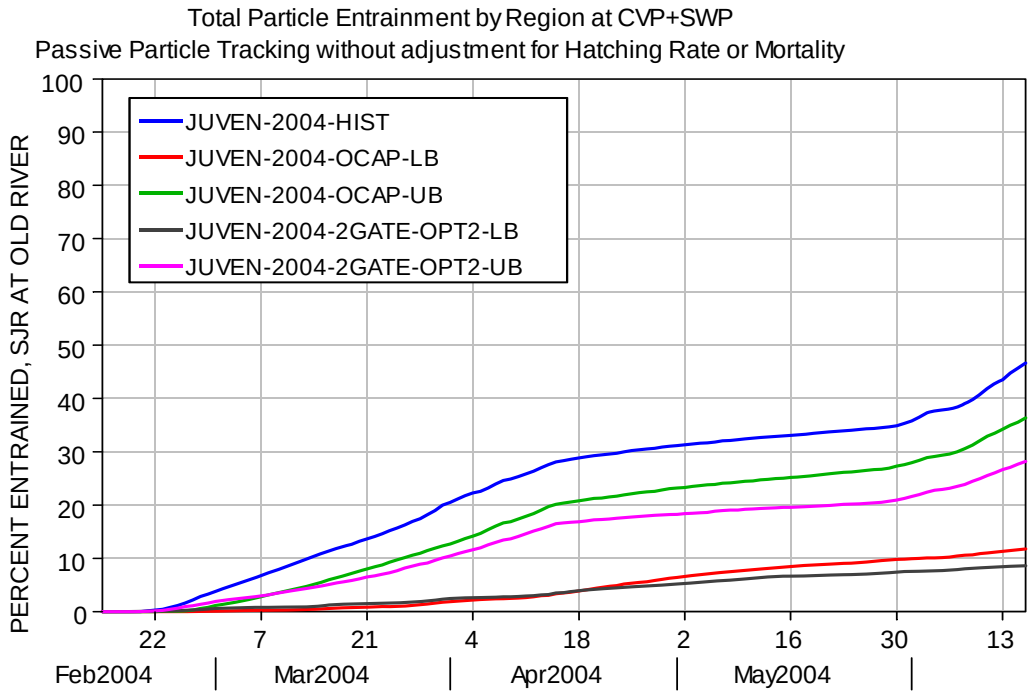

Figure 71 Percent particles entrained at the CVP+SWP originating from the region "SJR at Old River".

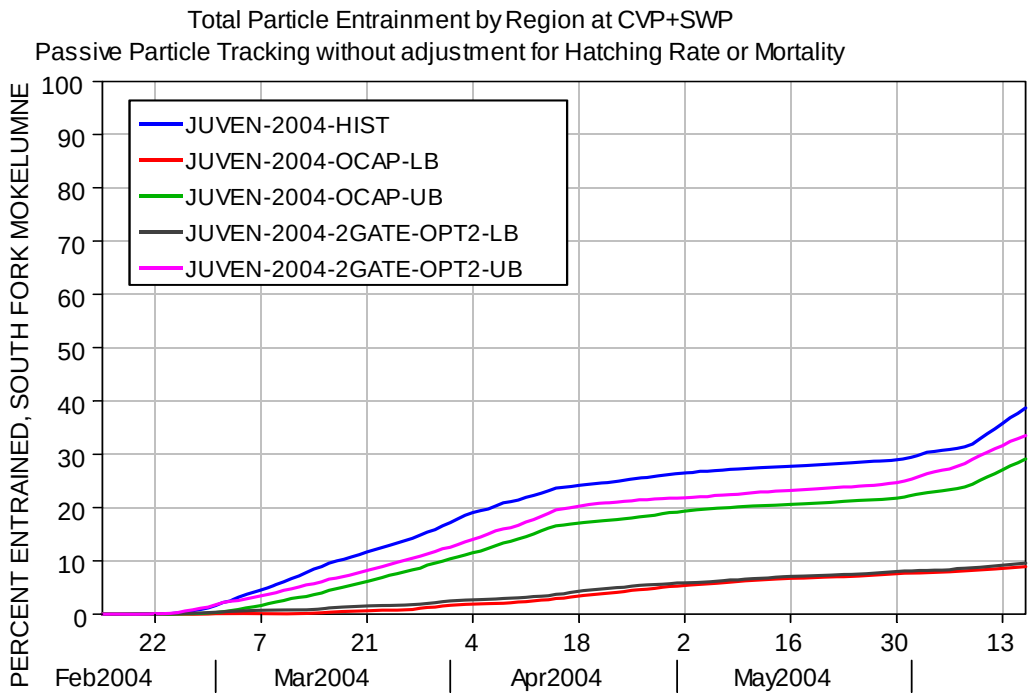

Figure 72 Percent particles entrained at the CVP+SWP originating from the region "South Fork Mokelumne".

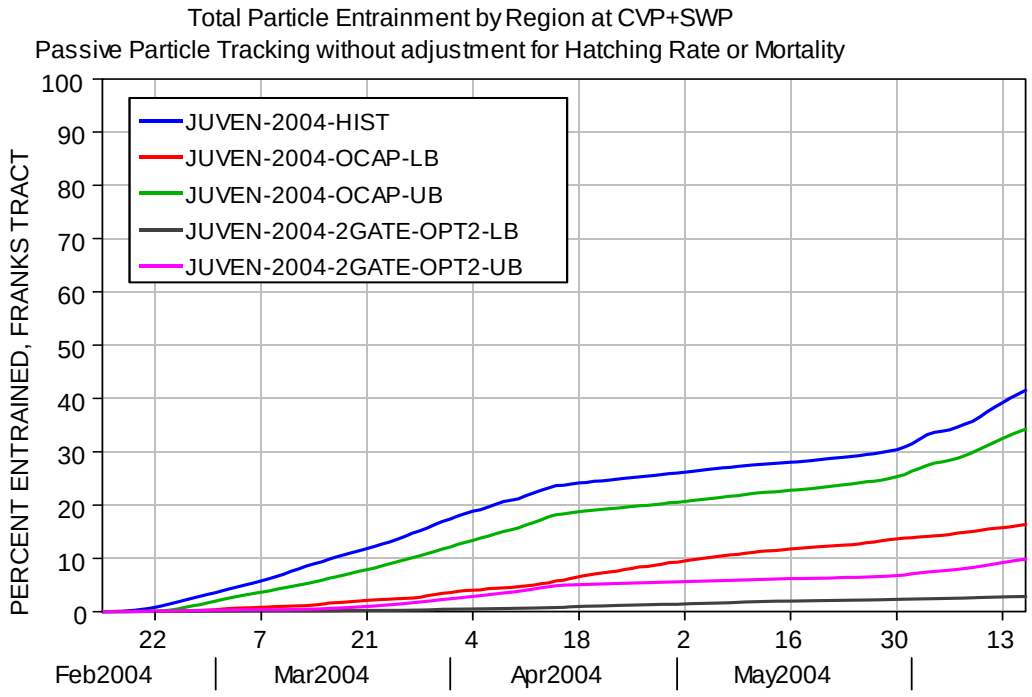

Figure 73 Percent particles entrained at the CVP+SWP originating from the region "Franks Tract".

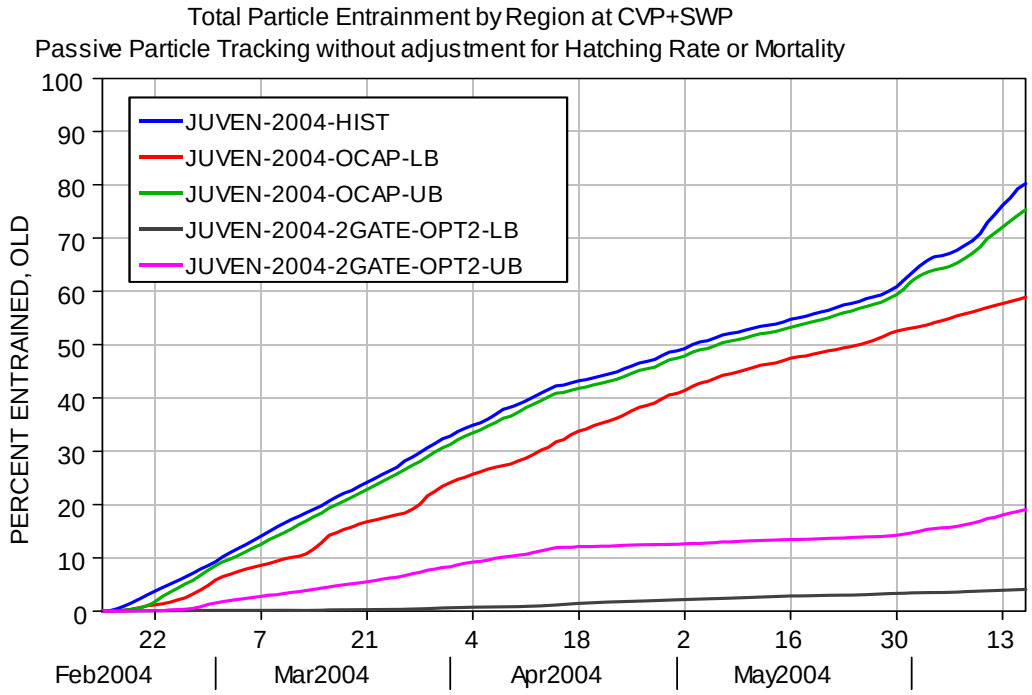

Figure 74 Percent particles entrained at the CVP+SWP originating from the region "Old".

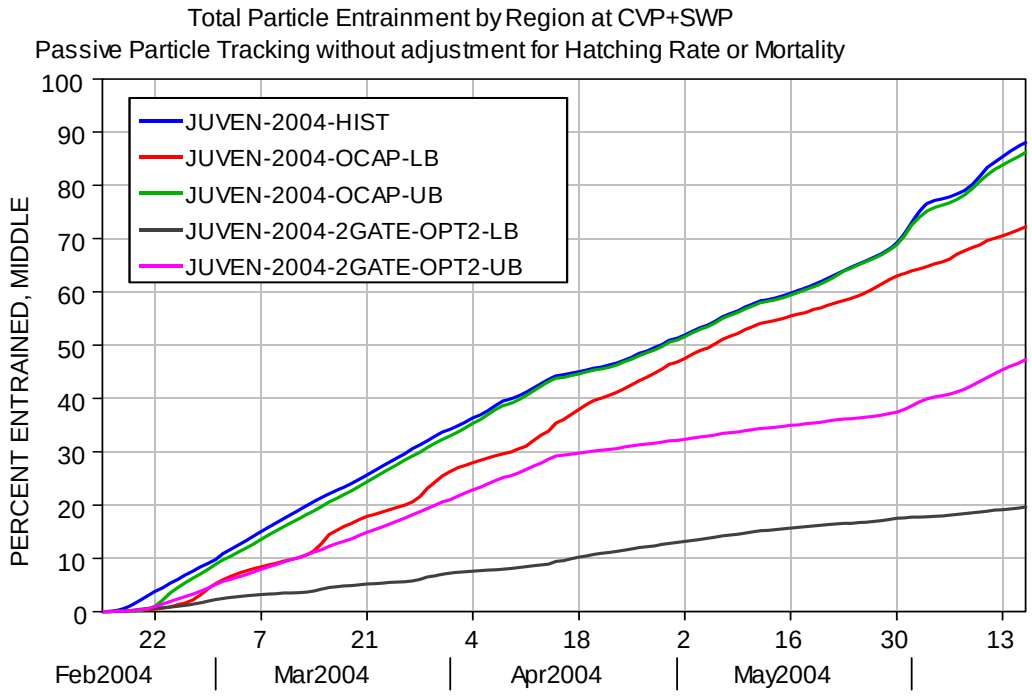

Figure 75 Percent particles entrained at the CVP+SWP originating from the region "Middle".

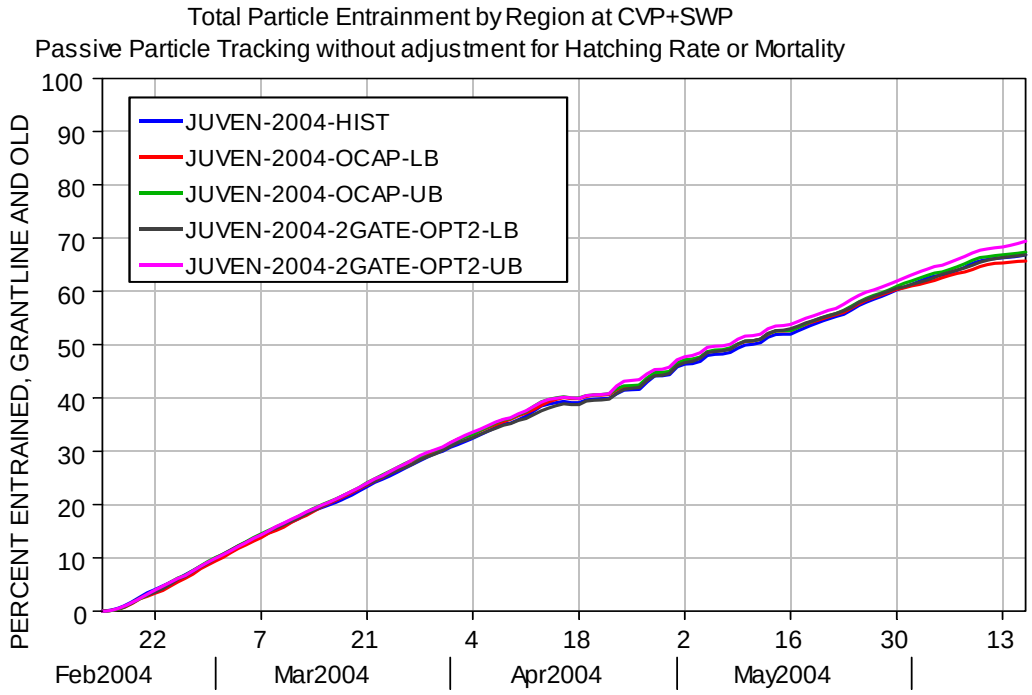

Figure 76 Percent particles entrained at the CVP+SWP originating from the region "Grantline and Old".

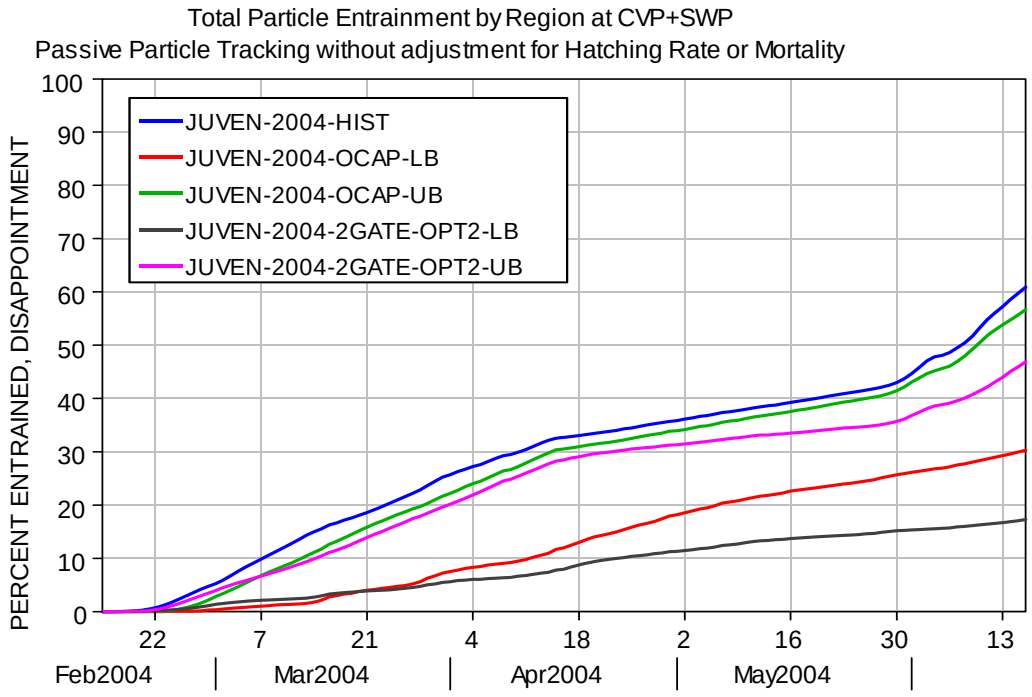

Figure 77 Percent particles entrained at the CVP+SWP originating from the region "Disappointment".

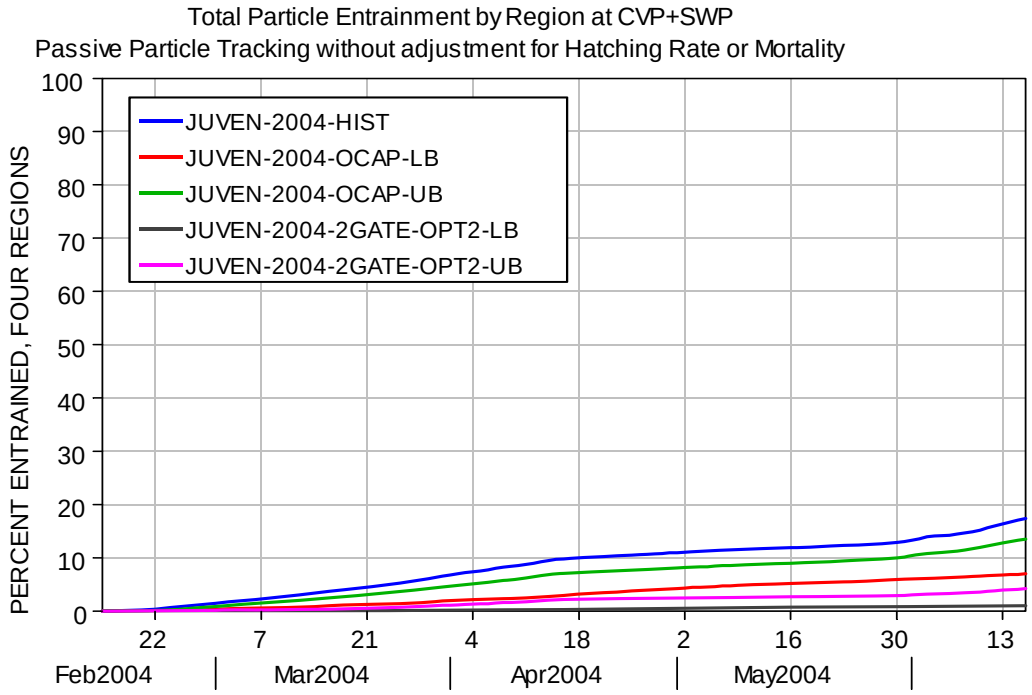

Figure 78 Percent particles entrained at the CVP+SWP originating from "SJR near confluence," "SJR near False River," "Franks Tract," and "Old" regions.

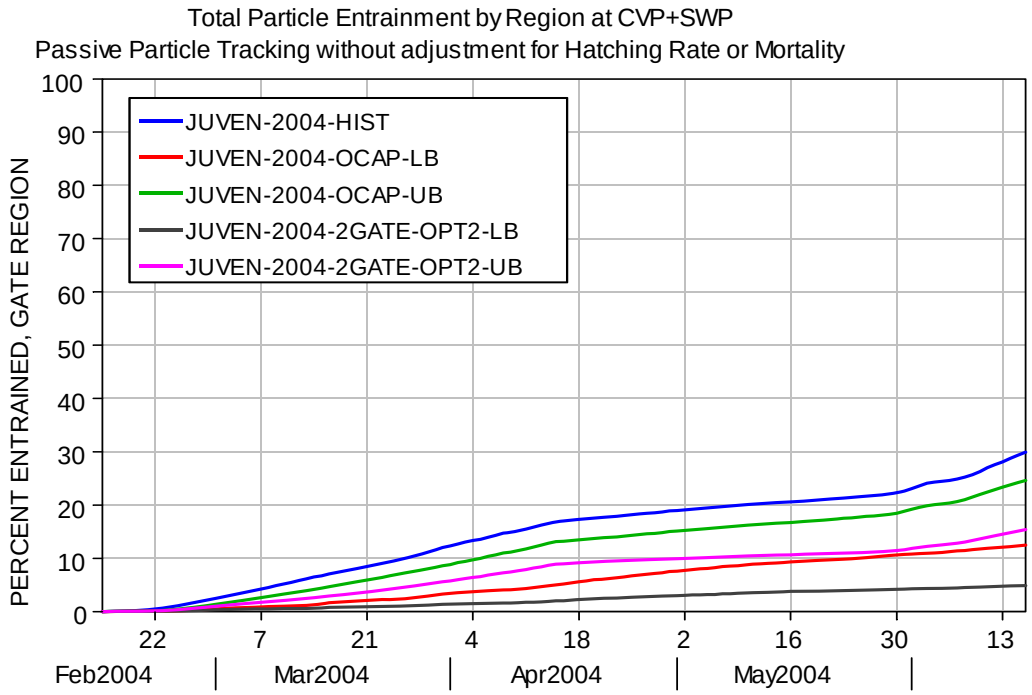

Figure 79 Percent particles entrained at the CVP+SWP originating from the region of influence of the gates, including "SJR near confluence," "SJR near False River," "SJR at Old River," "Franks Tract," "South Fork Mokelumne," "Disappointment," "Middle," and "Old" regions.

Summary

Numerical modeling analysis of potential entrainment of adult, juvenile, and larval delta smelt has been performed in support of the 2-Gates Demonstration Project. The objective of the modeling analysis was to examine the incremental benefit of operable barriers in Old River and Connection Slough relative to conditions under proposed OCAP flow requirements in Old and Middle River.

Two distinct particle tracking techniques were used to represent the adult life stage and the larval/juvenile life stages. 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 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.

To simulate Larval and Juvenile delta smelt, 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 were derived through an automated tuning algorithm that develops a best fit estimate of regional hatching rates from the historic 20mm Trawl Surveys. However, due to the uncertainty in the analysis process leading to historic hatching distributions and the current inability to link changes in the adult distributions with changes in hatching distributions, alternative analysis of larval/juvenile delta smelt based on hatching distributions was not pursued at this time. The analysis was done based on percent entrainment by region. Better approaches for estimating hatching distributions with linkage to adult distributions will be investigated in ongoing efforts.

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. Results of this modeling analysis should be evaluated in light of the assumptions and limitations of the modeling approach identified in this report.

The modeling exercises performed to date suggest that use of operable barriers in Old River and Connection Slough in conjunction with restriction of negative Old and Middle River (OMR) flow may provide equal or greater protection for delta smelt than the application of restriction of OMR negative flow alone. In some conditions the 2-Gate project can allow increased exports over those provided under strict interpretation of the OCAP BO while continuing to provide equal or greater protection for delta smelt.

Adult delta smelt entrainment in the CVP and SWP exports may be greatly reduced or eliminated by maintaining a low turbidity region along the Old and Middle River corridors through strategic reduction of exports (restriction of negative OMR flow) combined with operation of the 2-Gate project to balance the turbidity flux from the central Delta along Old and Middle Rivers. Given the existing channel configuration, turbidity from the Sacramento River tends to move faster along Old River corridor from Franks Tract toward the CVP-SWP export locations than it does along the Middle River corridor (Figure 80). The 2-Gate project can be operated to shift net flow from Old River to Middle River to balance the turbidity flux along Old and Middle Rivers and maintain a larger region of low turbidity to act as a barrier for movement of adult smelt toward the export locations (Figure 80 and Figure 81). It is important to note that during some years, turbidity associated with very large San Joaquin outflow may overwhelm the ability to maintain a low turbidity region in the OMR corridor.

Entrainment in the CVP and SWP exports of larval and juvenile delta smelt that are hatched in a broad region of the central and southern Delta may be reduced by operating the 2-Gate project to increase dispersive mixing toward the lower San Joaquin River. This dispersive mixing may also improve habitat in the Sacramento-San Joaquin confluence area by facilitating westward transport of dissolved and suspended material (i.e. phytoplankton) originating in the upper San-Joaquin River and central and southern Delta. When the Old River gate is operated such that it is open on ebb and closed on flood, a net circulation is created downstream on Old River and upstream on Middle River that increases mixing between Franks Tract and the San Joaquin River (Figure 82). For this operation to be successful, total export pumping should be managed so that the conveyance capacity of Middle River is not exceeded and there should be sufficient Delta inflow to ensure strong positive downstream flow in the San Joaquin River below the junction with the Mokelumne River. Both of these conditions will be met if negative OMR flows are restricted per the OCAP BO and Delta inflows are not significantly reduced from historic levels. Total entrainment of larval and juvenile delta smelt may be expected to decrease with the 2-Gate open on ebb operation if the distribution of hatching is such that regions where entrainment is reduced (central and southern Delta) are more important than regions where entrainment is increased (Mokelumne River and Sacramento River above Georgiana Slough) (Figure 83).

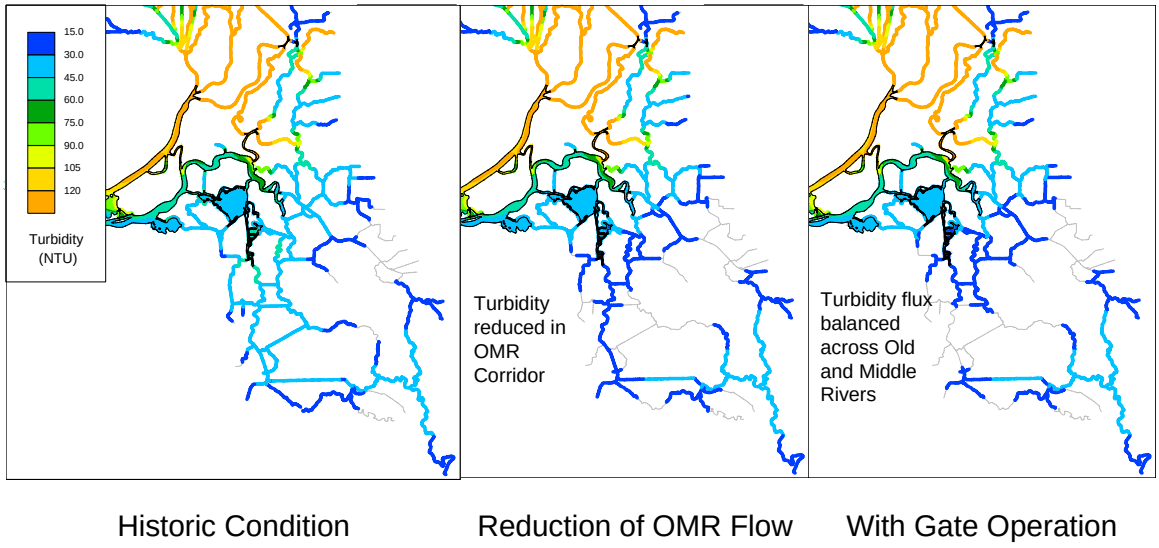

Figure 80 Operation of 2-Gates to reduce adult delta smelt entrainment by balancing turbidity flux along Old and Middle Rivers. Turbidity simulation result for January 17, 2003 at 0600.

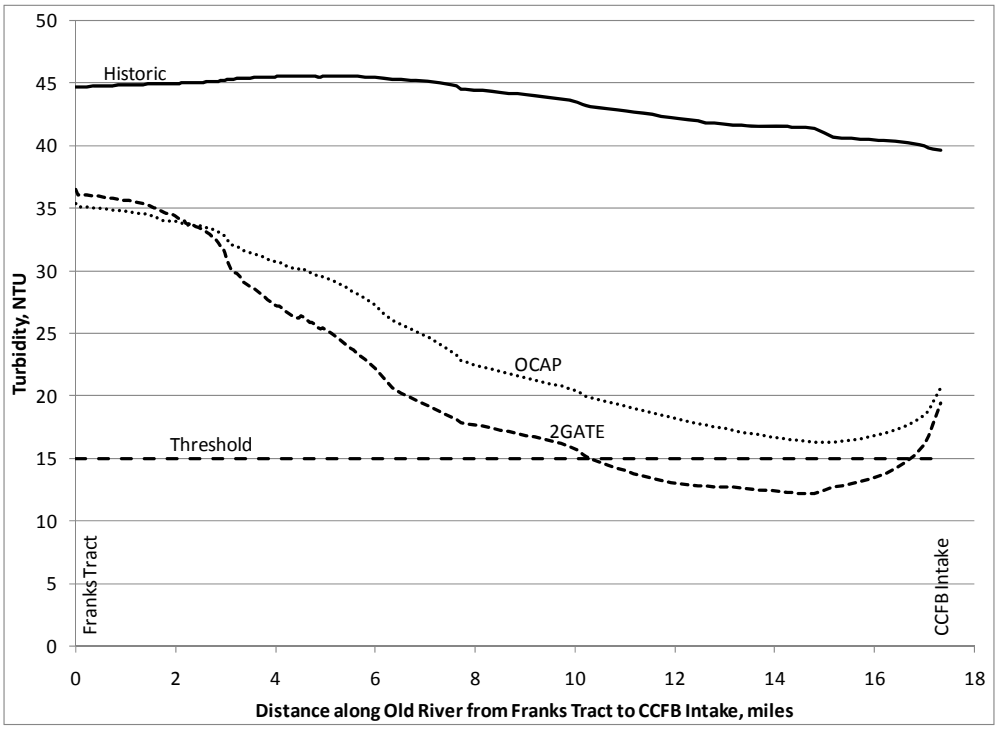

Figure 81 Turbidity profile along Old River turbidity simulation result for January 17, 2003 at 0600.

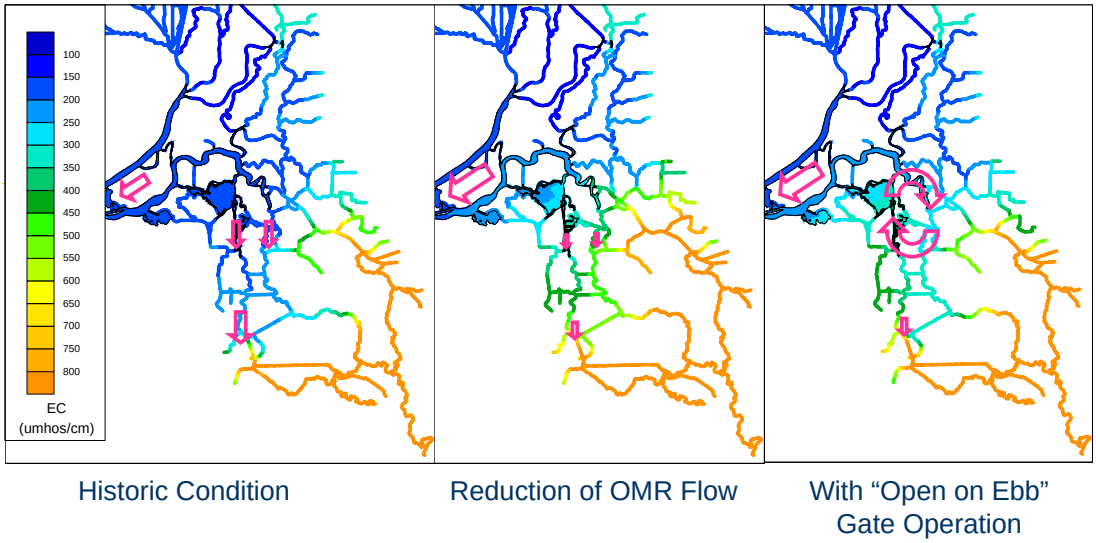

Figure 82 Operation of 2-Gates to reduce larval/juvenile delta smelt entrainment by increasing dispersive mixing through Franks Track toward the western Delta . EC simulation result for April 11, 2003 at 0000.

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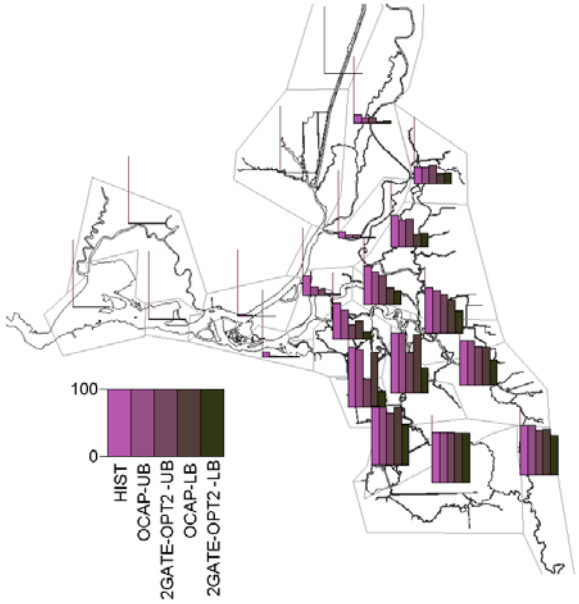

Figure 83 Percentage particles entrained at CVP+SWP from each region during the period February 15 - June 15, 2003.

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