Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

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Chapter 7
DSM2-PTM Simulations of Particle Movement

Authors: Yu Zhou and Tara Smith
Delta Modeling Section
Bay-Delta Office
California Department of Water Resources

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Contents

Figures

Tables

7 DSM2-PTM Simulations of Particle Movement

7.1 Summary

The National Marine Fisheries Service (NMFS) requested the California Department of Water Resources (DWR) Modeling Support Branch perform a DSM2-PTM modeling study to investigate the impact of various factors on salmon/steelhead migration behaviors in the Sacramento-San Joaquin River Delta (the Delta). Those factors include San Joaquin River (SJR) flows, exports from the State Water Project (SWP) and Central Valley Project (CVP), and the Head of Old River Barrier (HORB). The report documents the assumptions, model setups, and simulation results and could be used to help studies on HORB installation/operation and export adaptive management for salmonid outmigration protections.

7.2 Study Scenario Determination and Modeling Configuration

7.2.1 Hydrodynamic Boundary and Source Flows Configuration

The assumed flow and operations for these scenarios are synthetic but based on Delta historical hydrodynamic record and facilities operations. Although representing historical conditions, the synthetic hydrology allows only one flow or operation to be varied so that the impacts on particle movement due to the various changes can be more easily analyzed. The factors of concern are SJR flow, exports (CVP, SWP), and HORB operation; other boundaries and facilities are configured as fixed, using values associated with the selected intermediate SJR condition (red in Table 7-1).

May 2007 SJR monthly flow at Vernalis is closest to 3,000 cfs, a historical average flow in May (Table 7-1), so May–June 2007 was selected as the simulation period. Other boundaries, which are not of this study's concern, were set constant in the above simulation period. Figure 7-1 and Table 7-2 show the details of the Delta flow and stage boundary conditions.

Table 7-1 Monthly Average of San Joaquin and Sacramento River Flows in May, 1990 to 2010

Year	MAY monthly average flow (cfs)		Year	MAY monthly average flow (cfs)		Year	MAY monthly average flow (cfs)	
	SJR	SAC R.		SJR	SAC R.		SJR	SAC R.
1990	1,279	10,402	1997	4,530	11,349	2004	2,684	12,487
1991	1,049	7,332	1998	17,834	48,250	2005	10,380	40,079
1992	892	6,414	1999	5,681	19,723	2006	26,708	52,804
1993	3,610	24,955	2000	4,881	20,406	2007	3,033	9,204
1994	1,973	8,848	2001	3,637	9,082	2008	2,748	8,819
1995	22,187	63,181	2002	2,798	12,921	2009	2,185	15,436
1996	8,422	40,113	2003	2,691	40,514	2010	4,889	17,238

SJR: San Joaquin River flow at Vernalis; SAC R.: Sacramento River flow at Freeport; Red: selected; Green: max/min

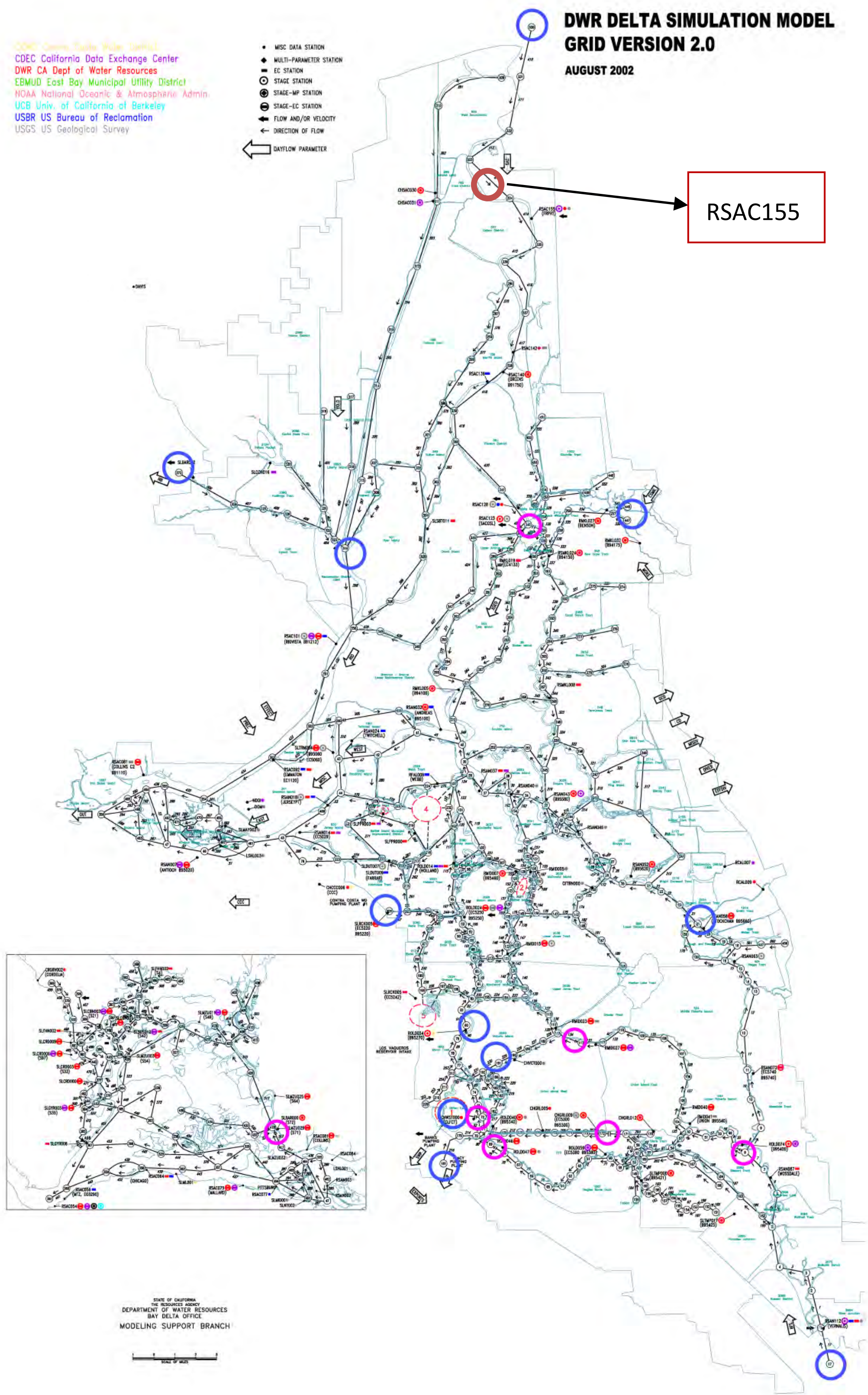

Figure 7-1 Delta Boundaries Showing Flows (blue circles) and Temporary Barriers and Gates (purple circles)

Table 7-2 DSM2-HYDRO Configuration for the Delta Boundaries and Source Flows

Source	DSM2			Flow (cfs)
	Name	Station	Node	
San Joaquin River	SJR	RSAN112	17	Vary for specific scenario
Sacramento River	SAC	RSAC155	330	Determined from sensitivity study[1]
Calaveras River	CALAVERAS	RCAL009	21	167.39
Cosumnes River	COSUMNES	RCSM075	446	214.58
Mokelumne River	MOKE	RMKL070	447	212.32
North Bay	NORTH_BAY	SLBAR002	273	99.871
Yolo Bypass	YOLO	BYOLO040	316	581.32
Contra Costa Canal	CCC	CHCCC006	206	96.636
Contra Costa Canal at Old River	CCCOLDR	ROLD034	80	87.164
Contra Costa Canal at Victoria Canal	CCW	CHVCT001	191	0
Central Valley Project	CVP		181	Vary for specific scenario
California State Water Project	SWP		Clifton Court	Vary for specific scenario
Martinez (stage)	May-June 2007 historical stage data			
DICU	May 2007 historical data			

7.2.2 Operable Barrier and Gate Configuration

The effect of HORB operations is the focus of this study. Two HORB operations were considered in the modeling studies: HORB is installed (HORB IN) and HORB is not installed (HORB OUT). When HORB is installed, all 6 HORB culverts are modeled as open to allow partial flow through the barrier into Old River (Le, 2004) (Division of Operations and Maintenance, 1989).

For the other temporary barriers, Middle River Barrier (MIDB), Grant Line Canal Barrier (GLCB), and Old River Barrier at Tracy (ORTB) were set in place with their pipes allowing one-directional flow to capture the incoming tide. Delta Cross Channel (DCC) was closed during the entire simulation period.

Historical May-Jun 2007 operations were used for Montezuma Salinity Control Structure (MTZSL).

The Priority 3 operation schedule was used for Clifton Court Forebay Gates (CLFCT). The Priority 3 gate operation is open 1 hour after the low-low tide, closed 2 hours after the high-low tide, reopened 1 hour before the high-high tide, and closed 2 hours before the low-low tide (Figure 7-2). Martinez historical tidal cycle stage data was delayed 5.5 hours for CLFCT to identify the peak, High-High tide (HH), Low-High tide (LH), Low-Low tide (LL), and High-Low tide (HL)).

Table 7-3 and Figure 7-1 show the barriers and gates operations discussed above.

[1] In order to identify an acceptable fixed value for SAC R. flow, a sensitivity analysis was conducted. The sensitivity analysis examines the effects of SAC R. flows at Freeport on the particle flux.

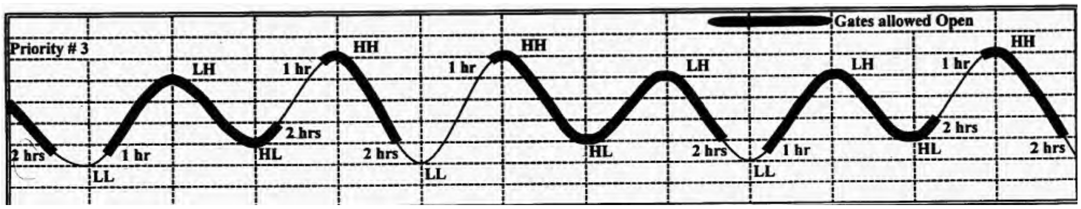

Figure 7-2 Priority 3 Operation Rule

Table 7-3 Facilities Configuration for the Delta Temporary Barriers and Important Gates

Facility	DSM2			INSTALL	weir		pipe		Flow direction
	name	node	chan		Elev (ft)	Width (ft)	number	Elev (ft)	
Head of Old River Barrier	HORB	8	54	IN/OUT	10	167	6	-4	both
Old River Barrier at Tracy	ORTB	69	79	IN	2	180	9	-6	Chan -> Node
Middle River Barrier	MIDB	112	134	IN	1	140	6	-4	Node -> Chan
Grant Line Canal Barrier	GLCB	206	172	IN	1	125	6	-6.5	Chan -> Node
Delta Cross Channel	DCC	342	365	CLOSED					both
Montezuma Salinity Control	MTZSL	418	512	historical op configuration					both
Clifton Court Forebay Gate	CLFCT	72	clifton_ court	'Priority 3' apply on 5.5 hrs delayed MTZ historical stage					Node -> Reservoir

7.2.3 Hydrodynamic Scenario Configuration

There are 2 sets of hydrodynamic scenarios in this study. For a given scenario, SJR flows and combined CVP+SWP exports will be the same (Table 7-4).

The first set of simulations is based on the ratio of the SJR flow at Vernalis to the export level (IE ratio) as defined in the NMFS Reasonable Prudent Alternatives (RPA). This set of simulations consists of:

- 4 levels of Vernalis flows
- Exports according to the IE ratio in the NMFS RPA
- 2 different configurations of the Head of Old River barrier (HORB-IN and HORB-OUT)

The second set of simulations is based on different combinations of SJR flow at Vernalis, and Old and Middle River flows (OMR). This set of simulations consists of:

- 4 levels of Vernalis flows
- 3 levels of OMR flows
- 2 different configurations of the Head of Old River barrier (HORB-IN and HORB-OUT)

For both sets of the scenarios, exports were equally split between CVP and SWP, i.e., CVP = SWP. Because of flood safety concern, HORB is not installed when SJR flow is equal to or greater than 12,000 cfs. This safety restriction reduced the total scenarios to 36.

Aside from the specific combinations above, these 2 scenario categories are different in the way in which input variables vary. These could bring in very different hydrodynamics, especially for SJR branches to the South Delta. This may result in very different particle movement:

- SJR_IE scenarios could reflect the export directly, and could vary SJR flow and export together, i.e., proportionally when fixing IE ratio (in the following analysis expressed as 'varying SJR flow' for convenience);
- SJR_OMR scenarios could vary SJR flow and exports independently, and could use OMR to reflect the hydro conditions close to the exports more directly.

Table 7-4 Simulation Hydro Combinations of sjr_ie Scenarios and sjr_omr Scenarios

SJR_IE			SJR_OMR		
SJR Flow (cfs)	**IE Ratio**	**Total**	**SJR flow (cfs)**	**OMR (cfs)**	**Total**
1,500	1:1	16 scenarios	1,500	-2,500, -3,500, -5,000	24 scenarios
3,000	1:1, 2:1		3,000	-2,500, -3,500, -5,000	
4,500	2:1, 3:1		6,000	-2,500, -3,500, -5,000	
6,000	3:1, 4:1		12,000 (only HORB-OUT)	-2,500, -3,500, -5,000	
12,000 (only HORB-OUT)	4:1				

7.2.4 DSM2-PTM Configuration

For the particle insertion locations selection, there are 2 scenarios: Three Basins and Southern Delta (Table 7-5, Figure 7-3); each scenario has its own flux outputs configuration (Table 7-6).

Each insertion location is treated as 1 PTM simulation in every Hydro scenario. Thus, there are in total 36 x (3 + 7) = 360 PTM simulations. For each PTM simulation, 10,000 particles are inserted at a fixed rate such that they are all inserted within the 24 hours of the start of the simulation.

Table 7-5 PTM Particle Insertion Location Scenarios

Scenario	Insertion	DSM2 node	Description	Output group
Three Basins	Mossdale	6	Mossdale	Standard output; SJR junctions output;
	Calaveras	21	San Joaquin River at Calaveras River	
	Rio Vista	351	Rio Vista	
Southern Delta	HOR	48	Just inside Head of Old River	Standard output
	Turner	140	Just inside Turner Cut	
	Columbia	31	Just inside Columbia Cut	
	Mmid	134	Just inside mouth of Middle River	
	Mold	103	Just inside mouth of Old River	
	Jersey	469	San Joaquin River just downstream of Jersey Point	
	3mile	240	Just inside Threemile Slough	

The PTM running period is set as 45 days. The starting time is set as the midpoint between the neap and spring tides.

Figure 7-4 shows the historical Martinez tidal stage at Station RSAC054. May 7 is in the middle between its spring and neap. Figure 7-5 shows that the corresponding San Joaquin flow is 3,012 cfs, which is close to our required May monthly average. Therefore, May 7 is selected as the PTM simulation starting date. June 20 is selected as the ending date.

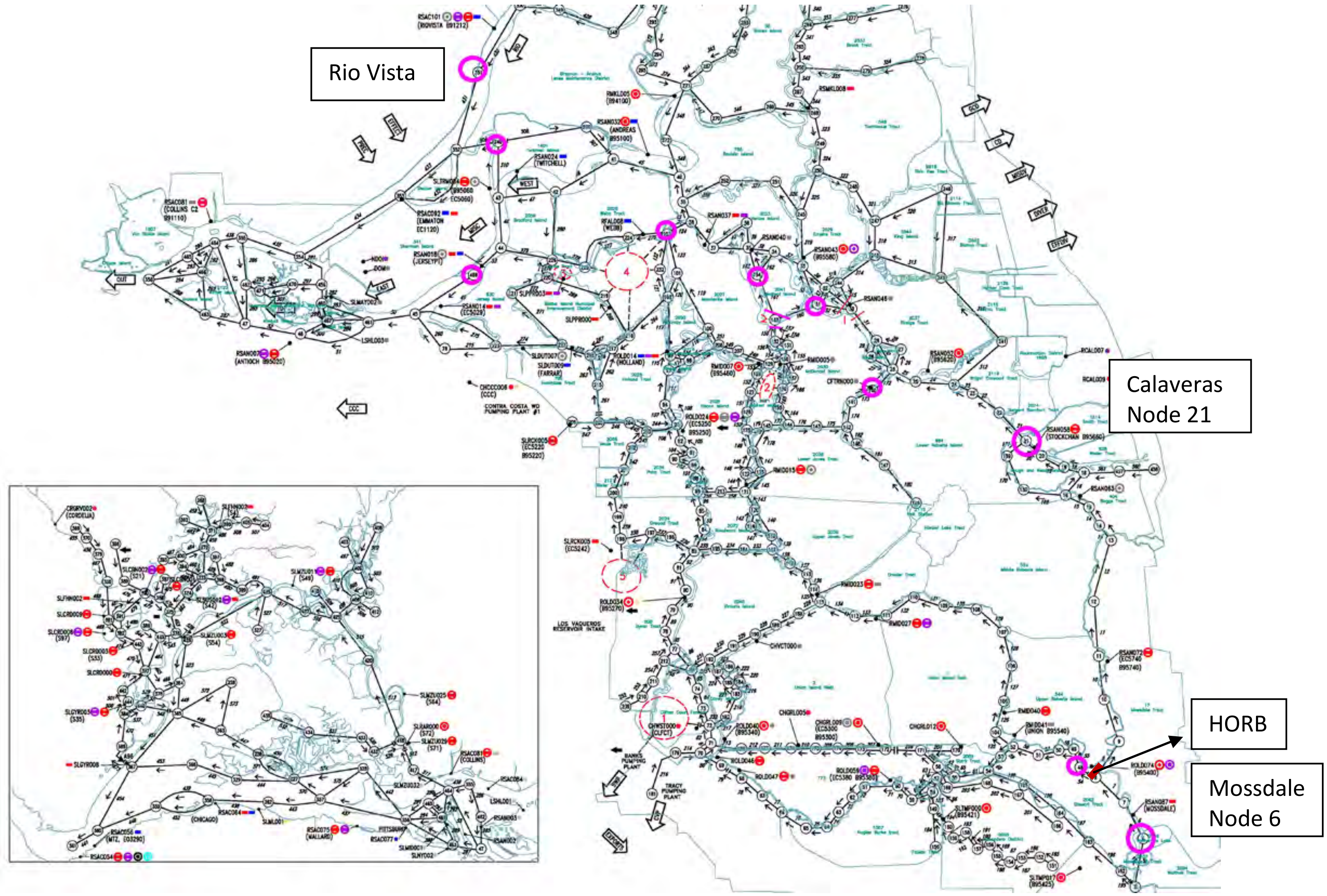

Figure note: Big circles indicate 3 locations of the 'three basins' scenario; small circles indicate 7 locations of the Southern Delta scenario

Figure 7-3 PTM Particle Insertion Locations (purple circles)

Table 7-6 PTM Flux Output Groups and Specification

Scenario	Name	Description	DSM2 water body		Related Hydro chan
			From	To	
PTM Standard Boundary Output * particle fate for Delta	DIVERSION_AG	Particles by agricultural facilities (DICU)	all	ag_div	N/A
	DIV_CCC	Particles diverted by Contra Costa Canal	ccc_chan	ccc_div	
	EXPORT_CVP	Particles diverted by CVP	216	CVP	
	EXPORT_SWP	Particles diverted by SWP	clifton_court	SWP	
	PAST_MTZ	Particles passing Martinez	441	mtz	
	WHOLE	Particles remaining in Delta (not yet diverted)	whole		
South Delta SJR Output * particle split pattern for SJR junctions	hor_sjr	San Joaquin River at Head of Old River to just inside Head of Old River	7,8	54	54
	sjr_hor	San Joaquin River at Head of Old River to San Joaquin River just downstream of Head of Old River	7,54	8	8
	turner_sjr	San Joaquin River at Turner Cut to just inside Turner Cut	25,26,27,30	172	-172
	sjr_turner	San Joaquin River at Turner Cut to San Joaquin River just downstream of Turner Cut	25,172	26,27,30	26-27+30
	columbia_sjr	San Joaquin River at Columbia Cut to just inside Columbia Cut	32,33,35	160	-160
	*sjr_columbia_up	San Joaquin River upstream at Columbia Cut to San Joaquin River just downstream of Columbia Cut (indirectly apply)	31,314	32,34, 315,316	31+314
	sjr_columbia	San Joaquin River at Columbia Cut to San Joaquin River just downstream of Columbia Cut	sjr_columbia_up - columbia_sjr		
	mmid_sjr	San Joaquin River at Mouth of Middle River to just inside Mouth of Middle River	162,163	161	161
	sjr_mmid	San Joaquin River at Mouth of Middle River to San Joaquin River just downstream of Mouth of Middle River	40,41	42	40+41
	rold_sjr	San Joaquin River at Mouth of Old River to just inside Mouth of Old River	42,43	124	-124
	sjr_rold	San Joaquin River at Mouth of Old River to San Joaquin River just downstream of Mouth of Old River	42,124	43	43
	jersey	Past Jersey Point	83	49	49
	3mile_sac	Sacramento River at Threemile Slough to just inside Three Mile Slough *(For Rio Vista insertion point only)*	431,432,433	309	-309
	sac_3mile	Sacramento River at Threemile Slough to Sacramento River just downstream of Three Mile Slough *(For Rio Vista insertion point only)*	431,309	432,433	432+433

Table note: Blue (shaded) cells indicate SJR junction mainstream branch downstream to Martinez.

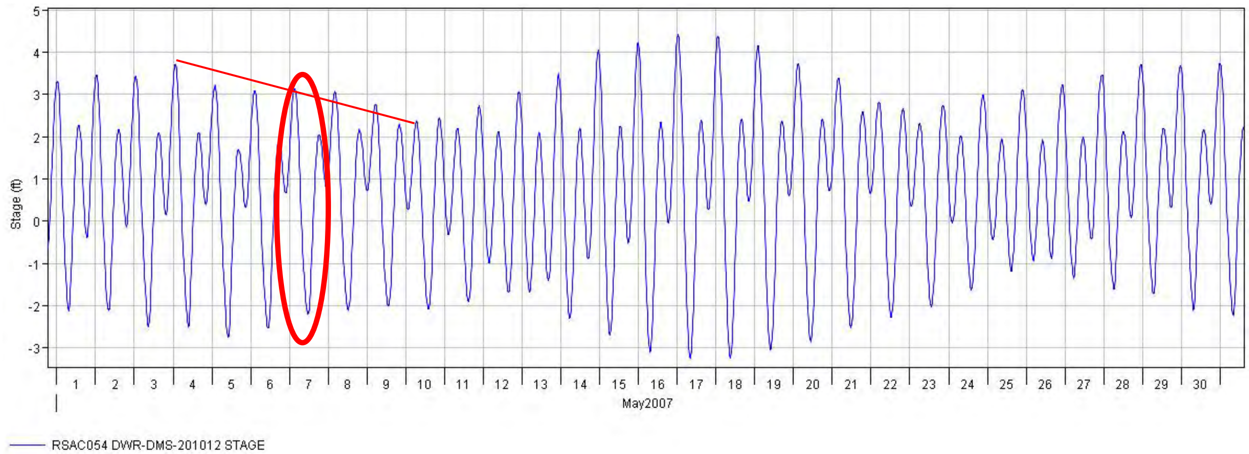

Figure 7-4 Stage at Martinez at Station RSAC054

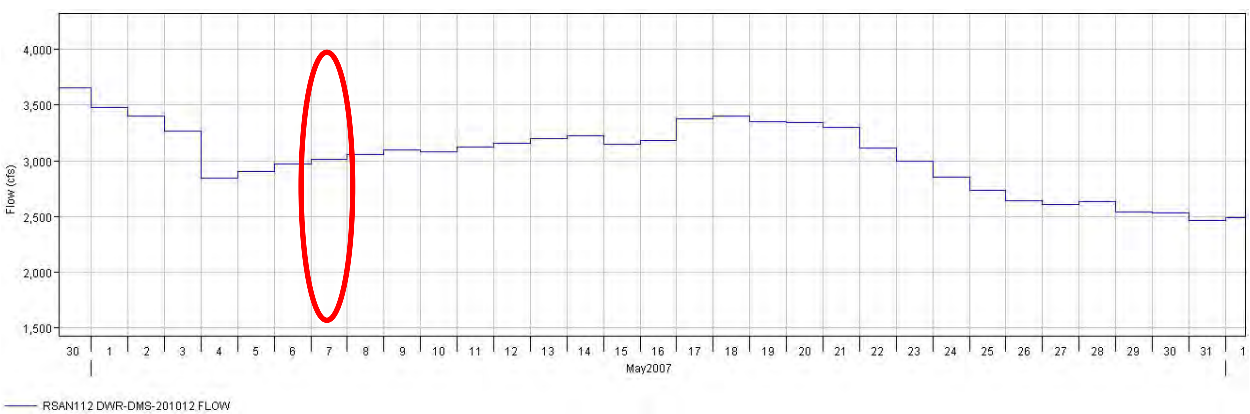

Figure 7-5 San Joaquin River Flow at Station RSAN112

7.3 Sacramento River Flow Sensitivity Test

7.3.1 Simulation Configuration

In order to examine the influence of Sacramento River (SAC R.) flows on particle movement and fate, a sensitivity analysis was conducted with a range of Sacramento River flows. This sensitivity analysis was done to see if it was necessary to add an additional matrix of runs where the Sacramento River flow varied. If the sensitivity simulations indicate that the impact of the Sacramento River is not significant then only one value of Sacramento flow would be used in the simulations and the other parameters such as San Joaquin River flow, exports, and Old River at Head Barrier configuration varied.

This sensitivity analysis is configured with the intermediate SJR flow condition (3000 cfs), IE ratio of 1:1 (both CVP and SWP exports are at 1500 cfs). The other inputs including boundary conditions and barriers/gates operations are the same as described in the previous Section of this report.

To cover the varying range of the SAC R. flows, the following values were selected (Table 7-7):

- 6400 cfs: historical minimum SAC R. May monthly-average flow, Year 1992
- 63200 cfs: historical maximum SAC R. May monthly-average flow, Year 1995
- 9200 cfs: historical SAC R. May monthly-average flow with the medium SJR flows, Year 2007
- 20000 cfs and 40000 cfs: 2 values in the middle between the minimum and maximum

Particles are inserted at DSM2 nodes 6, 21, and 351 (i.e., 3 basin insertion scenario in Table 7-5 and Figure 7-3) with the standard PTM flux output configuration.

Table 7-7 HYDRO Configuration for SAC R. Sensitivity Analysis

Source	DSM2			Flow (cfs)
	Name	**Station**	**Node**	
San Joaquin River	SJR	RSAN112	17	3000
Sacramento River	SAC	RSAC155	330	6400, 9200, 20000, 40000, 63200
Central Valley Project	CVP		181	1500
State Water Project	SWP		clifton_court	1500

7.3.2 Result Summary

The Sacramento flow amount only has significant influence on the percentage of particles moving past Martinez. With Sacramento River flow increased, the percentage of particles moving past Martinez increases. The influence of the Sacramento River flow amount on other output locations are relatively small and not uniform. (Please refer to the authors for detailed analysis on each insert location).

The effect of the Head of Old River Barrier depends on the particle insertion location.

- With HORB-IN, the percentage of particles moving into the CVP decreases for Mossdale insertion location and increases for Calaveras insertion location.
- The barrier’s influence on SWP is relatively small, possibly due to the operation effect of the tidal operation gate at Clifton Court Forebay.
- The barrier’s influence on the percentage of particles moving past Martinez (increase) is significant only for Mossdale insertion. Its influence on other fluxes is relatively small.

Understanding the relative impacts of Sacramento flow levels and using that understanding in interpreting the results, the remainder of simulations for the requested sets of studies used 18,000 cfs for Sacramento boundary flow.

7.4 Hydrodynamic Scenario Results and Analysis

A series of Hydro simulations were conducted for both SJR_IE and SJR_OMR scenarios. OMR flow and flow splits at some key junctions of San Joaquin River were recorded.

7.4.1 Old and Middle River (OMR)

The combined flow of Old River and Middle River (OMR) is used as one criterion to decide the 2nd set of hydrodynamic scenarios. In DSM2, OMR is determined by adding flows at the following 3 channels:

OMR = $Q_{144} + Q_{145} - Q_{106}$. Note that negative flow in channel 106 is due to the channel direction defined in DSM2. (Table 7-8)

The calculated OMR timeseries are processed with Godin filter and 14-day forward moving average; then average over the entire period. This final average is used as the indicator for OMR criterion.

Table 7-8 Locations Required for OMR Calculation in DSM2 Grid

	Channel	Node	Channel Direction
Old River	106	93	To node 93
Middle River	144	121	To node 121
	145	121	To node 121

7.4.1.1 San Joaquin River Flow – IE Ratio (sjr_ie) Scenarios

Table 7-9 and Figure 7-6 show all the SJR_IE scenarios with corresponding hydro conditions. Detailed OMR comparisons are in Appendix B-1.

a) For the same SJR flow, as IE Ratio increases (lower export, same SJR flow), OMR flow increases (negative flow decreases), for both HORB-IN & OUT.
b) For the same IE Ratio, as SJR flow increases (export increases proportionally), OMR flow decreases (negative flow increases) at smaller SJR, but the decrease rate gradually becomes less, finally reverses to increase (negatively decrease) at higher SJR flow, for both HORB-IN & OUT. This is because SJR flow increases more than export, with the same increase ratio.
c) Concerning the difference between HORB-IN and OUT:

- HORB-OUT has relatively a more stable OMR trend over the entire period.
- OMR IN-OUT difference is always negative, i.e. same sjr_ie conditions would result in more negative OMR for HORB-IN, since HORB-IN block SJR flow entering Old River, then more OMR flow is required for the same export.
- For the same SJR flow, as IE Ratio increases, OMR IN-OUT difference increases a little bit,
  i.e. varying export causes the same OMR change for HORB-IN & OUT.
- For the same IE Ratio, as SJR flow increases, OMR IN-OUT difference negatively increases, i.e. larger SJR flow and export combination has negative larger OMR for HORB-IN.

Table 7-9 Hydro Conditions for sjr_ie Scenarios

				OMR		IN-OUT	
Scenario	SJR	CVP+SWP	IE Ratio	HORB-IN	HORB-OUT	OMR diff	OMR diff ratio (over HORB-OUT)
sjr1500_ie11	1500	1500	1	-2045.14	-1648.64	-396.50	0.24
sjr3000_ie11	3000	3000	1	-3282.05	-2415.77	-866.28	0.36
sjr3000_ie21	3000	1500	2	-1887.96	-1036.87	-851.09	0.82
sjr4500_ie21	4500	2250	2	-2438.21	-1092.27	-1345.94	1.23
sjr4500_ie31	4500	1500	3	-1741.27	-397.38	-1343.89	3.38
sjr6000_ie31	6000	2000	3	-2085.88	-163.00	-1922.88	11.80
sjr6000_ie41	6000	1500	4	-1621.03	302.79	-1923.82	-6.35
sjr12000_ie41	1500	3000	4	N/A	1864.19	N/A	

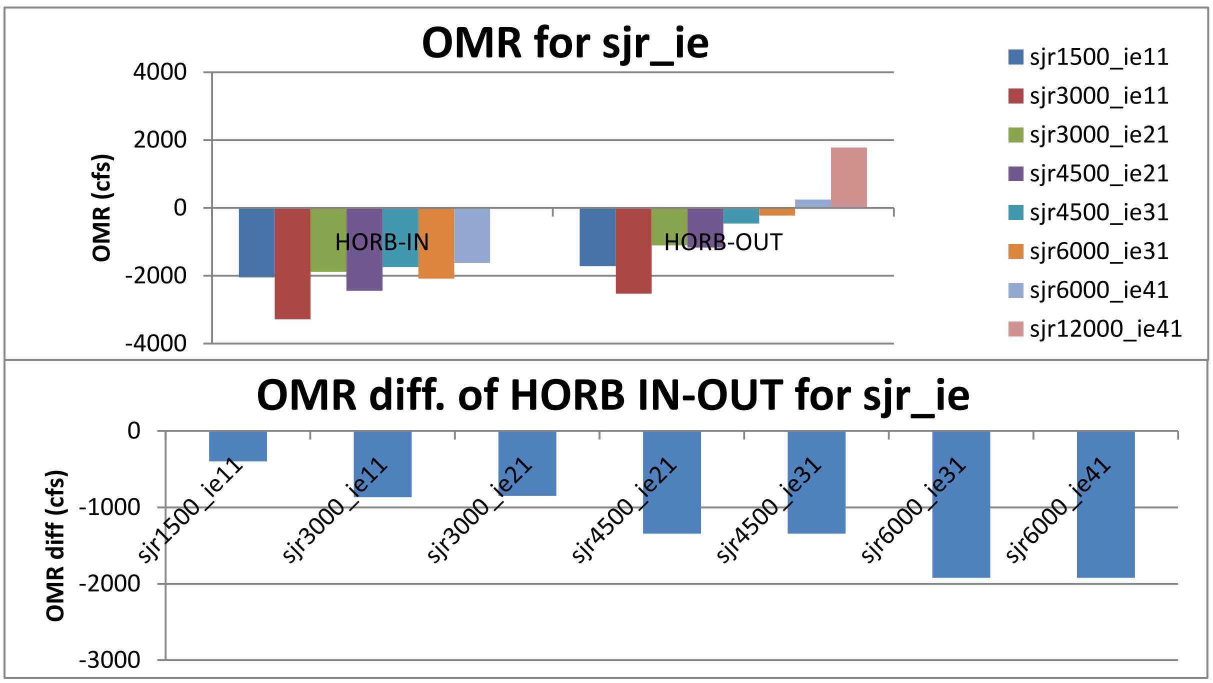

Figure 7-6 OMR and its HORB IN-OUT Difference for sjr_ie Scenarios

7.4.1.2 San Joaquin River Flow – OMR (sjr_omr) Scenarios

Because OMR flow is an output of DSM2, not an input, a trial-and-error iteration method is applied to achieve the required OMR flow with boundaries inputs (CVP, SWP) varying.

Table 7-10 and Figure 7-7 list all the sjr_omr scenarios with the corresponding hydro conditions. Detailed OMR comparisons are in Appendix B-2.

a) For the same SJR flow, as OMR negatively increases, export increases, IE ratio decreases, for both HORB IN and OUT; i.e., higher negative OMR standard allow larger export, especially for HORB-OUT.
b) For the same OMR, as SJR flow increases, HORB-IN export slightly increase, HORB-OUT export increases, IE ratio increases, for both HORB IN and OUT; i.e. for the same OMR standard, higher SJR flow allow more export.
c) Concerning the differences between HORB-IN and OUT:

- Export IN-OUT difference is always negative, IE Ratio IN-OUT difference is always positive, i.e., same sjr_omr conditions could allow more exports for HORB-OUT, since there is another water source (Old River) for export in addition to OMR.
- For the same SJR flow, as OMR negatively increases, export IN-OUT difference negatively increases slightly, IE Ratio IN-OUT difference decreases; i.e., higher OMR standard allows higher export, but similar increase for both HORB IN & OUT.
- For the same OMR flow, as SJR flow increases, export IN-OUT difference negatively increases and IE Ratio IN-OUT difference increases; i.e., for the same OMR, higher SJR flow could allow exports increase for both HORB IN & OUT, but more for HORB-OUT.

Table 7-10 Hydro Conditions for sjr_omr Scenario

			HORB IN		HORB OUT		IN - OUT	
Scenario	**SJR**	**Target OMR**	**CVP+SWP**	**Approx. IE Ratio**	**CVP+SWP**	**Approx. IE Ratio**	**CVP+SWP**	**IE Ratio**
sjr1500_omr2500	1500	-2500	2000	3/4	2400	5/8	-400	0.13
sjr1500_omr3500		-3500	3100	1/2	3500	3/7	-400	0.06
sjr1500_omr5000		-5000	4700	1/3	5200	2/7	-500	0.03
sjr3000_omr2500	3000	-2500	800	4/3	1700	1/1	-900	0.40
sjr3000_omr3500		-3500	2200	1/1	3100	5/7	-1000	0.22
sjr3000_omr5000		-5000	3200	5/8	4200	1/2	-1000	0.11
sjr6000_omr2500	6000	-2500	4800	5/2	5800	4/3	-2100	1.17
sjr6000_omr3500		-3500	2400	12/7	4500	1/1	-2100	0.64
sjr6000_omr5000		-5000	3500	7/6	5600	5/6	-2100	0.34
sjr12000_omr2500	12000	-2500	N/A		3850	14/9	N/A	
sjr12000_omr3500		-3500			4350	11/8		
sjr12000_omr5000		-5000			5150	7/6		

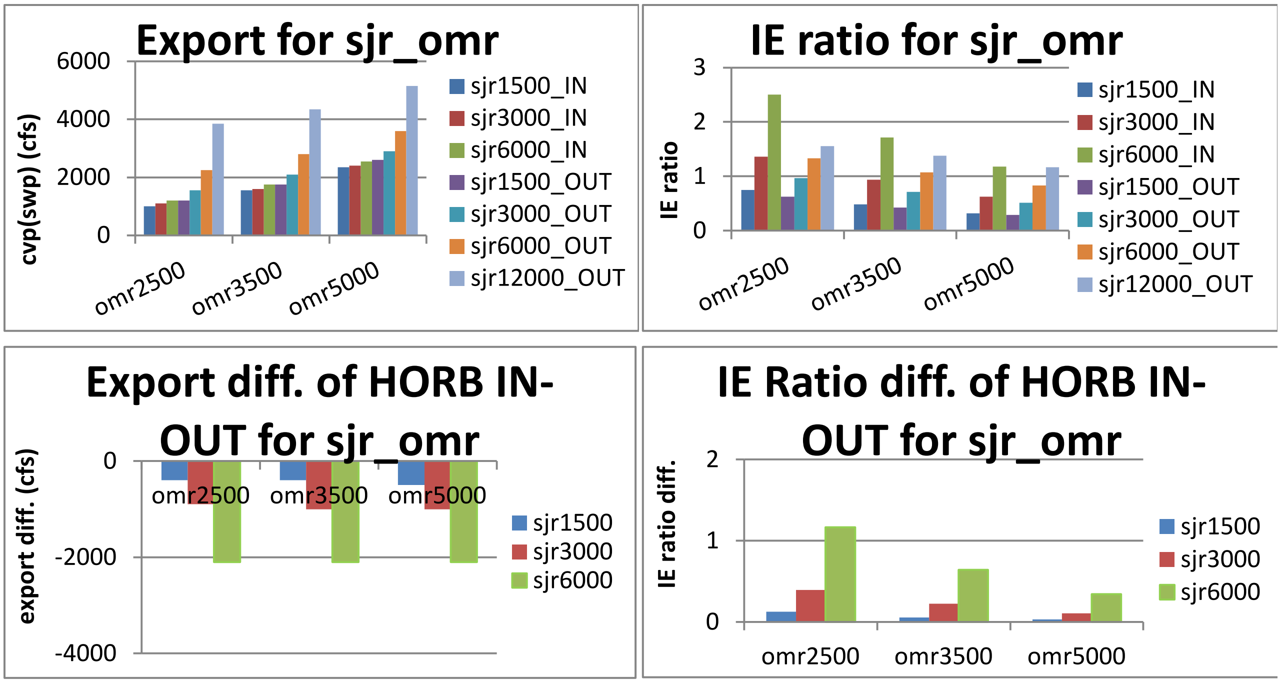

Figure 7-7 Export and IE Ratios and Their HORB IN-OUT Difference for sjr_omr Scenarios

7.4.2 Flow Splits at San Joaquin River Junctions to South Delta

The current version of the DSM2-PTM uses a purely flow-volume-driven particle movement model. In order to better investigate the particle movement environment at San Joaquin River key junctions—main stem downstream and branches to South Delta junctions include Head of Old River (hor), Tuner, Columbia (col), Middle River mouth (mmid), and Old River mouth (rold)—average flows of the entire 45-day simulation period were recorded for these locations (the last column of Table 7-6). Detailed comparative bar charts are included in Appendix B-3 (sjr_ie scenario), B-4, and B-5 (sjr_omr scenario).

- SJR (SAC R.) main stem usually takes the major flows, due to the large cross-section area.
- Flow ratios of downstream / (downstream + southward branch) are calculated to better represent the flow split pattern. This ratio is only calculated when both branch flows are positive. A negative ratio happens when one of the branches has flow direction inverse from specified direction, and cannot be used for the analysis & comparison.

7.4.2.1 San Joaquin River Flow – OMR (sjr_omr) Scenarios

The flow information of Appendix B-4, Appendix B-5 is summarized for all sjr_omr scenarios in the following ways: Table 7-11 lists the average flow ranges (minimum-maximum) of SJR junctions, as well as the flow ratios of downstream / (downstream + southward branch), and their IN-OUT difference. Table 7-12 and Table 7-13 list these flow variation patterns to SJR flow and OMR.

- As SJR flow increases (higher SJR flow, same export), usually both downstream and southward Delta branches increase in flow. There are some exceptions that experience flow decreases such as mmid and 3mile. This pattern is similar for both HORB-IN and OUT.
- As OMR increases (higher export, same SJR flow), usually downstream flow decreases and southward branch flows increase. This pattern is similar for both HORB-IN and OUT.

- Negative downstream flow appears at some output locations, including columbia, mmid, and rold, especially for high OMR and low SJR flow scenarios, i.e., more flows to South Delta. And usually the closer the locations to Chipps, the larger the negative flows, i.e., rold > mmid > columbia. Figure 7-8 shows the flow directions of channels around ROLD for sjr1500_omr11 scenario, other scenarios are similar.

HORB IN-OUT differences of average flows in sjr_omr scenarios:

- Usually have positive values, i.e., HORB-IN has more flow for both downstream and southward branches.
- Have some negative exceptions: (1) HOR branch – this is the branch after HORB; when HORB-OUT, flow passes through it. (Please refer to the authors for the detailed analysis) (2) Mmid, 3mile branch.
- Usually the closer the specified location to Chipps, the smaller the difference; e.g., jersey, 3mile have the difference < 10 cfs.
- Variation pattern is non-uniform. Usually all locations downstream increase with SJR flow.

The ratio of flow downstream / (downstream + branch) could indicate the flow split pattern more directly (the larger the ratio, the more particles flow to downstream):

- As <u>SJR flow increases</u> (higher SJR flow, similar export), the ratio usually increases, i.e., higher SJR flow increases both downstream and southward branch flows, but the latter more.
- As <u>OMR flow increases</u> (higher export, same SJR flow), the ratio usually decreases, which corresponds to larger downstream flow and smaller southward branch flow.
- Flow ratio IN-OUT difference is usually positive, i.e., HORB-IN direct more flows downstream. Variation pattern: (1) As OMR increases, IN-OUT difference usually increases, i.e., higher export with HORB-IN direct more flow downstream. (2) Its variation pattern to SJR flow is not uniform. As SJR flow increases, ratio decreases for Turner, Columbia, increases for 3mile.

7.4.2.2 San Joaquin River Flow – IE Ratio (sjr_ie) Scenarios

The flow information of Appendix B-3 is summarized for all sjr_ie scenarios, but not included in this report. (Please refer to the authors for the detailed analysis.)

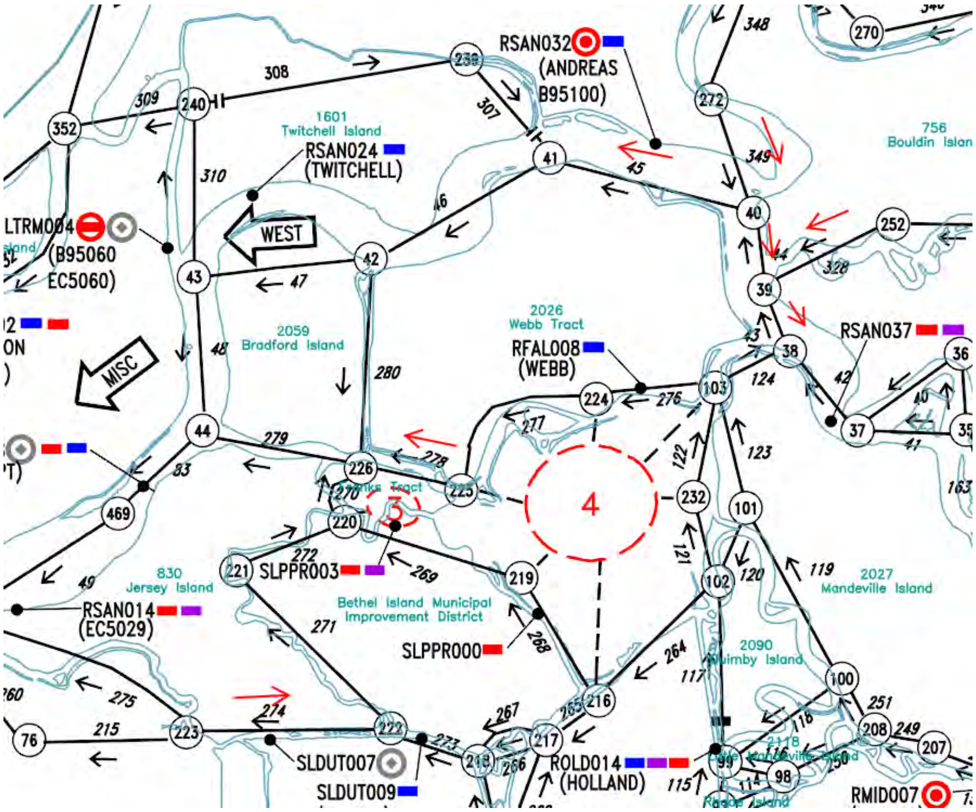

Figure 7-8 Flow Directions (red arrows) of Channels around ROLD for sjr1500_ie11 Scenario

Table 7-11 Average Flow (cfs) Range (min, max) for SJR Junctions in sje_omr Scenarios

Junctions	IN			OUT			IN-OUT		
	branch	downstream	ratio	branch	downstream	ratio	branch	downstream	ratio
HOR	(328.9, 794.9)	(987.9, 5033.2)	(0.7, 0.9)	(767.9, 2854.7)	(508.5, 2983.4)	(0.4, 0.5)	(-2059.8, -439.0)	(438.3, 2053.6)	(0.3, 0.4)
Turner	(374.3, 757.3)	(386.0, 4182.1)	(0.4, 0.9)	(346.5, 660.3)	(-33.0, 2344.9)	(0.2, 0.8)	(27.9, 97.0)	(381.2, 1837.2)	(0.0, 0.3)
Columbia	(331.0, 1396.5)	(-387.6, 3049.7)	(0.4, 0.8)	(259.3, 1084.1)	(-712.0, 1587.7)	(0.3, 0.7)	(71.8, 312.5)	(298.0, 1462.0)	(0.1, 0.3)
Mmid	(521.8, 1485.2)	(-1054.8, 2824.0)	(0.0, 0.8)	(706.6, 1539.9)	(-1386.4, 1383.1)	(0.2, 0.7)	(-200.6, -23.1)	(279.3, 1440.9)	(0.2, 0.4)
Rold	(3067.2, 4090.4)	(-4760.5, -653.1)	(0.0, 0.0)	(3011.3, 3909.0)	(-5056.6, -1901.6)	(0.0, 0.0)	(35.5, 192.2)	(223.4, 1257.8)	(0.0, 0.0)
Jersey	(0.0, 0.0)	(1014.5, 6306.5)	(0.0, 0.0)	(0.0, 0.0)	(611.9, 4653.1)	(0.0, 0.0)	(0.0, 0.0)	(312.3, 1663.0)	(0.0, 0.0)
3mile	(743.8, 1815.0)	(12303.4, 13468.2)	(0.9, 0.9)	(1069.2, 1885.3)	(12231.8, 13118.9)	(0.9, 0.9)	(-325.4, -57.0)	(57.9, 349.3)	(0.0, 0.0)

*Ratio is flow of downstream / (downstream + southward branch)

Table 7-12 Average Flow Variation Pattern with SJR Flow Increasing for SJR Junctions in sjr_omr Scenarios

<table>
<tr><th rowspan="2">Junctions</th><th colspan="3">IN</th><th colspan="3">OUT</th><th colspan="3">IN-OUT</th></tr>
<tr><th>branch</th><th>downstream</th><th>ratio</th><th>branch</th><th>downstream</th><th>ratio</th><th>branch</th><th>downstream</th><th>ratio</th></tr>
<tr><td>HOR</td><td rowspan="3">increase</td><td rowspan="7">increase</td><td rowspan="4">increase</td><td rowspan="3">increase</td><td rowspan="7">increase</td><td rowspan="4">increase</td><td>negatively increase</td><td rowspan="7">increase</td><td>mixed</td></tr>
<tr><td>Turner</td><td rowspan="2">increase</td><td rowspan="3">decrease</td></tr>
<tr><td>Columbia</td></tr>
<tr><td>Mmid</td><td>decrease</td><td>decrease</td><td>negatively increase</td></tr>
<tr><td>Rold</td><td>increase</td><td rowspan="2">N/A</td><td>increase</td><td rowspan="2">N/A</td><td>increase</td><td rowspan="2">N/A</td></tr>
<tr><td>Jersey</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td>3mile</td><td>decrease</td><td>increase</td><td>decrease</td><td>increase</td><td>negatively increase</td><td>increase</td></tr>
</table>

*Yellow cell indicate negative values for most scenarios

Table 7-13 Average Flow Variation Pattern with OMR Increasing for SJR Junctions in sjr_omr Scenarios

<table>
<tr><th rowspan="2">Junctions</th><th colspan="3">IN</th><th colspan="3">OUT</th><th colspan="3">IN-OUT</th></tr>
<tr><th>branch</th><th>downstream</th><th>ratio</th><th>branch</th><th>downstream</th><th>ratio</th><th>branch</th><th>downstream</th><th>ratio</th></tr>
<tr><td>HOR</td><td rowspan="5">increase</td><td rowspan="7">decrease</td><td rowspan="4">decrease</td><td rowspan="5">increase</td><td rowspan="7">decrease</td><td rowspan="4">decrease</td><td>negatively increase</td><td>increase</td><td rowspan="4">increase</td></tr>
<tr><td>Turner</td><td rowspan="2">mixed</td><td rowspan="3">mixed</td></tr>
<tr><td>Columbia</td></tr>
<tr><td>Mmid</td><td>negatively increase</td></tr>
<tr><td>Rold</td><td rowspan="2">N/A</td><td rowspan="2">N/A</td><td>decrease</td><td rowspan="2">increase</td><td rowspan="2">N/A</td></tr>
<tr><td>Jersey</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td>3mile</td><td>increase</td><td>decrease</td><td>increase</td><td>decrease</td><td>negatively mixed</td><td>mixed</td><td>increase</td></tr>
</table>

*Yellow cell indicate negative values for most scenarios

7.5 PTM Scenarios Results and Analysis

A series of PTM simulations were conducted as described in Section 7.2.4, with insertion locations as in Table 7-5 and Figure 7-3. Simulation results are summarized in the following sections, with corresponding analysis. Detailed Flux plots can be found in Appendixes C and D.

Particle fates at the 45-day end of the simulation period are also recorded and summarized. Compared to the time curve, particles' "final" fates could reflect their movements more directly. Comparison is made between different Hydro scenarios, to identify the effect of SJR flow, IE Ratio, OMR.

7.5.1 Particle Fate Comparison for PTM Standard Boundary Outputs

PTM standard output locations are investigated for the particles' fate at Delta boundaries (Table 7-6):

- Focus is on PAST_MTZ (MTZ), EXPORT_CVP (CVP), EXPORT_SWP (SWP), and DIVERSION_AG (AG).
- DIV_CCC is usually very stable and only takes a small percentage of total flux (0-2%).
- WHOLE could be viewed as a corresponding result related to the other outputs, and its variation trend is usually not obvious to analyze.

For this study, both Three Basins and Southern Delta insertions are investigated (Table 7-5). These insertion locations cover a large part of the Central and South Delta, and could be grouped into 4 categories:

- Insertion 6—on SJR mainstream before HORB
- Insertions 21, 140, 31, 134, 103—on SJR mainstream after HORB (upstream -> downstream).
- Insertions 351, 469, 240—close to Chipps. Usually the particle flux is very large (60-98%) for **MTZ**, very small (1-10%) for CVP, SWP, i.e., most of the particles flow to MTZ, no opportunity to exports.
- Insertion 48—on Old River just after HORB. Usually **AG, export** (mostly CVP) are very large, taking almost 100% (HORB-IN with AG as majority because particles stay longer in Old River due to the very low flows; HORB-OUT with CVP as majority), i.e., most of the particles flow to agricultural facilities and exports, no opportunity to Chipps. Insertion 48 could be viewed as a special insertion, with variation pattern different from other insertions, and won't be included in the following analysis.

7.5.1.1 San Joaquin River Flow – OMR (sjr_omr) Scenarios

Table 7-14 and Table 7-15 summarize the PTM standard output particle fate variations to OMR and SJR flow for sjr_omr scenarios (Appendix C-2, C-3). Both HORB-IN & OUT have a similar pattern most of the time:

a) As <u>OMR increases</u> (higher export, same SJR flow), MTZ decreases for all the insertions, almost all the CVP and SWP increase; almost all the AG decreases for insertions farther from Chipps, increases for insertions close to Chipps.
b) As <u>SJR flow increases</u> (higher SJR flow, same OMR), MTZ increases for all the insertions. CVP, SWP, and AG variation patterns are usually not uniform: with CVP and SWP increases, AG decreases for insertions farther from Chipps and low SJR flows; with CVP and SWP decrease, AG increases for insertions close to Chipps and high SJR flows.

7.5.1.2 San Joaquin River Flow – IE Ratio (sjr_ie) Scenarios

The PTM standard output particle fate range and variation patterns for IE Ratio and SJR flow for sjr_ie scenarios (Appendix C-1) are summarized for all sjr_ie scenarios, but not included in this report. (Please refer to the authors for the detailed analysis.)

7.5.2 HORB IN-OUT Difference of Particle Flux at Martinez

In order to investigate the effect of HORB and HORB IN-OUT, differences of Martinez particle flux are examined for the required insertions. Similar analysis has been conducted for other outputs, e.g., CVP, SWP, but is not included in this report due to space limits. The results could be used for helping decision making of HORB installation in spring season.

- For insertion 6 (SJR upstream before HORB), usually HORB-IN brings more particles to Martinez, and IN-OUT differences increase as SJR flow increases and export decreases (OMR flow negatively decreases).
- For insertion 48, most of the particles flow to exports (CVP/SWP) or AG, that is, usually not to MTZ (except for high SJR flows, like 12,000 cfs, but it does not have HORB-IN for comparison).

7.5.2.1 San Joaquin River Flow – IE Ratio (sjr_ie) Scenarios

Table 7-16 and Figure 7-9 summarize Martinez particle fate at 45-days for different particle insertions of sjr_ie scenarios (details in Appendix C-1).

a) For insertions 21, 140, 31, 134, 103, 351, 469, and 240 (SJR downstream after HORB), HORB-OUT usually has much greater particle movement to Martinez, especially at higher SJR flows. This is probably because HORB-OUT results in lower flows at SJR junctions to the south Delta. Insertions 140, 31, 134, and 103 could have differences of -5% to -20% for SJR flow > 4,500 cfs. HORB's effect are small on insertions 351, 240, and 469; since insertions are very close to Chipps, most particles (usually >85%) go to MTZ.
b) Increasing SJR flow could negatively increase this IN-OUT difference.

7.5.2.2 San Joaquin River Flow – OMR (sjr_omr) Scenarios

Table 7-17 and Figure 7-10 summarize MTZ particle fate at 45 days for different particle insertions of sjr_omr scenarios. (Details in Appendix C-2 and C-3)

- IN-OUT difference is always positive (or zero) in the specified ranges. This is probably because HORB-OUT results in lower SJR flows, but the flows at SJR junctions to the South Delta do not change much with the same OMR flow in each hydro scenario.
- For particle flux HORB IN-OUT difference, the effect on OMR and SJR flow depends on the distance of the insertion location from Chipps:
  - Higher negative OMR usually reduces the difference for farther insertions (6, 21, 140, 31, 134, and 103), but enlarges the difference for the closer insertions (351, 469, and 240).
  - Higher SJR flow usually enlarges the difference for farther insertions (6, 21, 140, 31, 134, and 103), but non-uniform effect for the closer insertions (351, 469, and 240).
  - IN-OUT difference can be very large (5%-25%) for many insertions with higher SJR flow and negatively higher OMR.

Table 7-14 Particle Fates' Ranges (min, max) of PTM Standard Outputs at 45-days' End for sjr_omr Scenarios, Unit %

	MTZ		CVP		SWP		AG	
Insert	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**
6	(0.0, 30.1)	(0.0, 5.8)	(15.7, 31.4)	(26.5, 47.4)	(10.0, 28.4)	(5.8, 29.0)	(17.4, 40.5)	(14.5, 42.0)
21	(0.0, 35.5)	(0.0, 12.0)	(14.2, 37.1)	(7.8, 32.1)	(16.7, 35.8)	(20.6, 51.1)	(10.4, 22.2)	(12.4, 21.7)
140	(0.0, 10.7)	(0.0, 5.0)	(28.4, 42.3)	(13.8, 42.2)	(26.9, 44.2)	(33.4, 60.0)	(8.0, 19.4)	(7.1, 16.0)
31	(0.2, 37.6)	(0.1, 21.2)	(15.7, 42.0)	(8.4, 39.1)	(17.9, 41.6)	(27.9, 57.7)	(8.4, 17.5)	(7.2, 14.4)
134	(0.6, 50.3)	(0.3, 30.8)	(11.1, 41.5)	(7.0, 38.4)	(12.8, 40.5)	(24.9, 52.1)	(8.3, 15.9)	(7.5, 13.7)
103	(20.7, 67.0)	(18.0, 57.7)	(5.8, 26.1)	(3.8, 26.2)	(8.1, 26.5)	(13.5, 31.0)	(7.3, 11.3)	(7.5, 10.1)
351	(81.9, 96.2)	(79.7, 94.6)	(0.1, 2.8)	(0.0, 3.4)	(0.1, 2.3)	(0.3, 3.2)	(1.2, 2.2)	(1.2, 2.6)
469	(65.4, 95.6)	(60.6, 92.9)	(0.3, 6.0)	(0.2, 7.5)	(0.2, 5.4)	(0.7, 6.9)	(1.4, 4.7)	(1.7, 4.7)
240	(64.1, 95.6)	(60.9, 91.2)	(0.4, 7.9)	(0.2, 8.4)	(0.3, 7.2)	(1.0, 9.3)	(1.2, 4.4)	(1.9, 4.3)
48	(0.0, 0.0)	(0.0, 0.0)	(4.9, 42.8)	(36.5, 75.0)	(0.0, 0.0)	(0.0, 17.4)	(48.4, 85.3)	(16.5, 53.7)

Table 7-15 Particle Fates' Variation Patterns of PTM Standard Outputs with OMR and SJR Flow for sjr_omr Scenario

<table>
<tr><th rowspan="2">Insert</th><th colspan="2">MTZ</th><th colspan="2">CVP</th><th colspan="2">SWP</th><th colspan="2">AG</th></tr>
<tr><th>As OMR increases</th><th>As SJR flow increases</th><th>As OMR increases</th><th>As SJR flow increases</th><th>As OMR increases</th><th>As SJR flow increases</th><th>As OMR increases</th><th>As SJR flow increases</th></tr>
<tr><td>6</td><td rowspan="9">decrease</td><td rowspan="9">increase</td><td rowspan="6">increase</td><td>increase</td><td rowspan="6">increase</td><td rowspan="3">increase</td><td rowspan="6">decrease</td><td rowspan="6">decrease</td></tr>
<tr><td>21</td><td rowspan="5">decrease</td></tr>
<tr><td>140</td></tr>
<tr><td>31</td><td rowspan="3">IN: decrease;
OUT: increase -> decrease</td></tr>
<tr><td>134</td></tr>
<tr><td>103</td></tr>
<tr><td>351</td><td rowspan="3">increase (very small)</td><td rowspan="3">decrease (very small)</td><td rowspan="3">Increase (very small)</td><td rowspan="3">decrease (very small)</td><td rowspan="3">increase (very small)</td><td rowspan="3">decrease (very small)</td></tr>
<tr><td>469</td></tr>
<tr><td>240</td></tr>
<tr><td>48</td><td colspan="2">No particle</td><td>increase</td><td>increase</td><td>decrease</td><td>increase</td><td>decrease</td><td>decrease</td></tr>
</table>

Table 7-16 HORB IN-OUT Difference of Martinez Particle Flux Fate at 45-day's End for sjr_ie Scenarios

Insert		sjr1500 _ie11	sjr3000 _ie11	sjr3000 _ie21	sjr4500 _ie21	sjr4500 _ie31	sjr6000 _ie31	sjr6000 _ie41
Three Basins	6	0.20	1.92	5.31	6.29	10.27	13.62	15.12
	21	0.85	0.74	1.51	3.37	4.42	-2.35	-1.47
	351	0.25	0.04	0.09	-0.11	-0.33	0.34	1.12
Southern Delta	48	0.00	0.00	0.00	0.00	0.00	0.00	-0.60
	140	0.29	-0.02	-1.14	-3.64	-5.88	-15.14	-18.52
	31	0.19	1.00	-0.61	-5.32	-5.84	-17.08	-16.30
	134	0.53	0.22	0.36	-3.24	-4.30	-10.24	-10.67
	469	-0.26	0.01	-0.21	-0.38	-0.14	-0.16	-0.34
	240	0.41	0.86	0.06	-0.21	-0.21	-0.01	-0.54
	103	-0.98	-2.97	-4.93	-6.10	-6.84	-11.04	-10.34

*Red cell indicate particle flux IN-OUT difference larger than 5%; Green cell indicate particle flux IN-OUT difference less than -5%

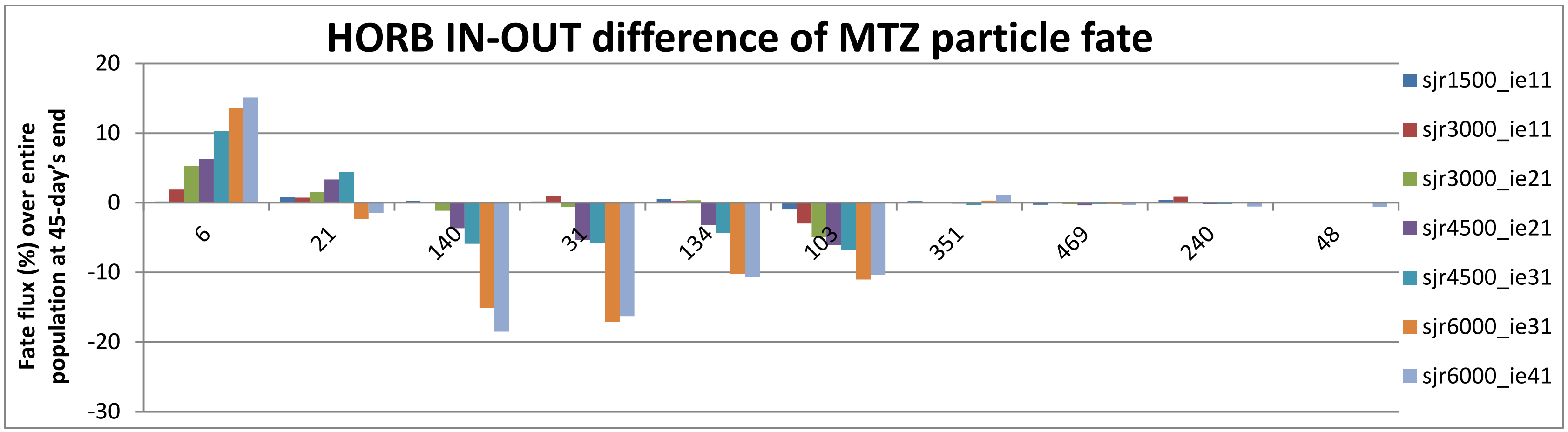

Figure 7-9 HORB IN-OUT Difference of Martinez Particle Flux Fate at 45-day's End for sjr_ie Scenarios

Table 7-17 HORB IN-OUT Difference of Martinez Particle Flux Fate at 45-day's End for sjr_omr Scenarios

Insert		sjr1500 _omr2500	sjr1500 _omr3500	sjr1500 _omr5000	sjr3000 _omr2500	sjr3000 _omr3500	sjr3000 _omr5000	sjr6000 _omr2500	sjr6000 _omr3500	sjr6000 _omr5000
Three Basins	6	0.12	0.08	0.00	4.36	2.16	0.46	24.30	17.09	7.43
	21	0.69	0.18	0.00	4.12	1.89	0.25	23.46	17.31	8.97
	351	0.78	1.74	2.30	1.87	2.46	4.59	1.57	4.09	4.25
Southern Delta	48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	140	0.43	0.08	0.01	1.49	0.43	0.07	5.75	4.14	1.89
	31	1.36	0.24	0.11	7.94	3.82	0.86	16.43	14.25	8.76
	134	2.51	0.72	0.31	9.18	7.00	2.11	19.47	19.66	14.44
	469	3.07	3.80	4.87	3.34	5.11	8.45	2.76	4.37	9.14
	240	2.83	2.77	3.18	4.41	7.10	6.79	4.44	5.63	11.05
	103	3.95	3.17	2.70	6.34	8.21	5.93	9.32	10.33	10.01

*Red cell indicates particle flux IN-OUT difference larger than 5%

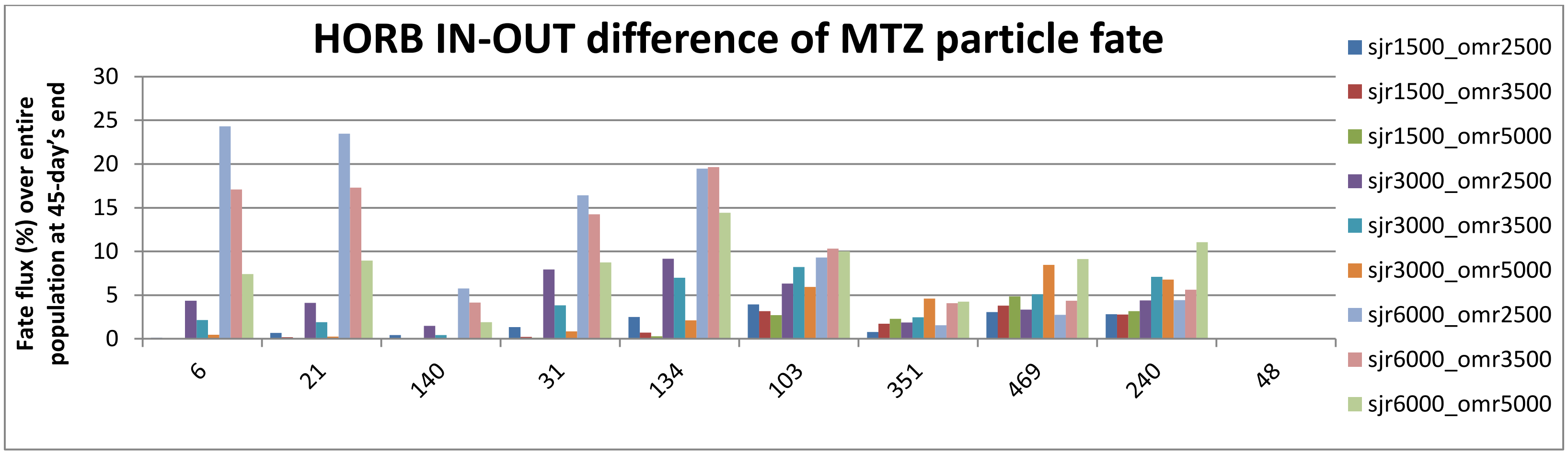

Figure 7-10 HORB IN-OUT Difference of Martinez Particle Flux Fate at 45-day's End for sjr_omr Scenarios

7.5.3 Particle Flux Split at San Joaquin River Junctions to Southward Branch

Another concern of this study is the particle flux split at SJR junctions of their main stem downstream and branches to South Delta (explained in Section 7.4.2). This split analysis is only for 3basins insertions: 6 (Mossdale), 21 (Calaveras), and 351 (Rio Vista).

Detailed comparative plots of particle fate at 45-days are included in Appendix D:

- For insertion 351, 3mile usually has particle flux 85-90% for sac_3mile, 10-15% for 3mile_sac, for both HORB-IN and OUT, both sjr_ie and sjr_omr scenarios. The variation pattern is stable and non-uniform with respect to SJR flow, IE ratio, and OMR. Therefore, 3mile is not considered further in this section.
- The downstream particle flux ratio is only included in the analysis when both branch particle fluxes are positive. A negative ratio happens when one of the branches has a net particle flux inverse from specified direction, and cannot be used for the analysis and comparison.

Average flow split analysis (Section 7.4.2) over the entire simulation period could be used as a reference for the particle movement environment. It cannot reflect the particle fluxes directly, because particles' split only take place at some specific times, e.g., HOR particles' split only take place in the first 2 days, thus only these 2 days flow split affects the particles' split pattern directly.

What should be clarified is the particle flux of DSM2-PTM is not based on particles, but connected water bodies (usually channels); e.g., one particle flowing through channel 1->2 would be counted 1, flowing through channel 2->1 would be counted -1. But one particle may be counted more than once if it reflows the same route; e.g., one particle flowing through channel 1->2->3->1->2 would be counted twice.

This situation may happen due to the complexity of the water bodies' grid and tide effect. As for the 2 categories outputs of this study (Table 7-6):

- Standard output locations (the previous 2 subsections) don't have this problem, since they are boundaries of the model, i.e., once out of boundaries, particles will never be counted again.
- SJR junctions (this subsection) have this problem, since they are intersection grids, and Martinez tide causes flows back and forth all the time. Their counts cannot reflect the exact real percentage of the entire inserted particle population.

However, this issue does not matter for the split analysis in this section. What is important is how particles split at those branch junctions, not which specific particles. Therefore, even if one reflow particle is recounted, it still reflects particles' split pattern at that junction, at that time. And the amount of these reflow particles is relatively limited due to the previous studies.

7.5.3.1 San Joaquin River Flow – OMR (sjr_omr) Scenarios

The particle flux information of Appendix D-3, D-4, D-5, and D-6 is summarized for all sjr_omr scenarios in the following ways: Table 7-18 lists the range (minimum, maximum) of particle flux fates at the 45-days, for SJR junctions, both HORB-IN & OUT and IN-OUT differences, as well as particle flux ratios of downstream / (downstream + southward branch), and their IN-OUT difference. Table 7-19 and Table 7-20 list the particle flux variation patterns to SJR flow and OMR.

- As SJR flow increases (higher SJR flow, similar export), usually downstream particle flux increases, southward branch particle flux increases for junctions close to Chipps (e.g. rold), decreases or non-uniform for junctions farther from Chipps (e.g. hor). This variation is similar for both HORB-IN and OUT, insertion 6 and 21.
- As OMR increases (higher export, same SJR flow), usually downstream particle flux decreases, southward branch particle flux decreases for junctions close to Chipps, increases for junctions farther from Chipps, non-uniform for junctions in-between. This variation is similar for both HORB-IN and OUT, insertions 6 and 21.

For HORB IN-OUT particle flux differences in sjr_omr scenarios,

- Usually positive difference value, i.e., HORB-IN has more flow for both downstream and southward branches since HORB-IN directs more flow to SJR mainstream.
- Some negative exceptions: (1) Insertion 6, HOR branch—this is the branch channel after HORB; HORB-OUT enables half SJR flows to enter interior Delta with almost half particles' fluxes. (2) Insertion 21, turner, columbia, and mmid have negative difference for high SJR flow, i.e., HORB-OUT has more southward flow than HORB-IN.
- Variation pattern is non-uniform. Usually insertions 6 and 21 have downstream increase with SJR flow for many junctions; insertion 6 has downstream decrease with OMR for junctions farther from Chipps.

Particle flux ratio of downstream / (downstream + southward branch) could indicate the particle flux split pattern more directly:

- As SJR flow increases (higher SJR flow, similar export), ratio of many junctions (both insertion 6 and 21) usually increase, i.e., higher SJR flow increases both south-branch and downstream particle flux, but the latter more.
- As OMR increases (higher export, same SJR flow), ratio of many junctions (both insertion 6 and 21) usually decrease, which corresponds to larger downstream particle flux and smaller south-branch particle flux.
- Ratio IN-OUT difference of many junctions is usually positive, i.e., HORB-IN makes larger downstream particle flux. Yet negative values also exist, especially for low SJR flow. This variation pattern is non-uniform to SJR flow and OMR.

7.5.3.2 San Joaquin River Flow – IE (sjr_ie) Scenarios

The particle split information of Appendix D-1 and D-2 is summarized for all sjr_ie scenarios, but not included in this report. (Please refer to the authors for the detailed analysis.)

Table 7-18 Particle Fate Ranges (min, max) at 45-day's End at SJR Junctions for sjr_omr Scenarios, Unit %

Loc	IN			OUT			IN-OUT		
	branch	downstream	ratio	branch	downstream	ratio	branch	downstream	ratio
6									
HOR	(13.0, 24.2)	(74.4, 86.7)	(75.4, 86.9)	(48.2, 56.5)	(42.0, 51.5)	(42.7, 51.6)	(-35.2, -29.0)	(29.1, 35.2)	(29.4, 35.3)
Turner	(7.7, 34.6)	(3.6, 39.2)	(9.4, 83.7)	(6.5, 24.4)	(24.0, 70.5)	(49.5, 91.5)	(-1.9, 10.2)	(-33.5, -20.4)	(-40.1, -7.9)
Columbia	(13.2, 25.4)	(8.6, 53.9)	(37.0, 80.4)	(1.8, 16.6)	(1.2, 25.5)	(39.6, 68.7)	(1.6, 14.1)	(7.4, 28.4)	(-3.5, 14.2)
Mmid	(8.0, 22.4)	(0.1, 44.5)	(1.1, 79.9)	(1.0, 14.9)	(0.0, 17.8)	(1.0, 66.9)	(2.1, 15.2)	(0.1, 26.6)	(0.1, 28.5)
Rold	(0.1, 30.6)	(0.0, 13.7)	(-11.1, 30.9)	(0.0, 14.3)	(0.0, 3.4)	(-5.9, 100.0)	(0.1, 18.1)	(0.0, 10.3)	(-111.1, 13.7)
Jersey	N/A	(0.0, 25.7)	N/A	N/A	(0.0, 7.7)	N/A	N/A	(0.0, 18.0)	N/A
21									
Turner	(15.6, 56.6)	(12.9, 78.3)	(18.5, 83.4)	(10.9, 72.6)	(32.8, 79.5)	(31.1, 88.0)	(-16.8, 4.7)	(-20.1, -1.2)	(-12.6, 5.7)
Columbia	(15.3, 33.2)	(12.4, 59.9)	(39.1, 79.7)	(7.6, 34.5)	(4.1, 52.7)	(34.8, 72.1)	(-11.6, 11.8)	(5.1, 13.3)	(1.6, 17.6)
Mmid	(10.2, 24.8)	(0.2, 51.3)	(1.5, 83.4)	(3.8, 28.5)	(0.0, 34.7)	(0.5, 62.0)	(-11.2, 8.7)	(0.2, 20.2)	(1.0, 34.7)
Rold	(0.2, 35.5)	(-0.1, 15.7)	(-27.8, 30.7)	(0.0, 28.7)	(0.0, 5.7)	(-0.5, 16.5)	(0.2, 17.2)	(-0.1, 10.0)	(-27.8, 14.7)
Jersey	N/A	(0.1, 29.9)	N/A	N/A	(0.0, 14.4)	(0.0, 0.0)	N/A	(0.1, 15.6)	N/A
351									
Jersey	N/A	(2.4, 13.8)	N/A	N/A	(0.9, 12.1)	N/A	N/A	(0.7, 3.4)	N/A
3mile	(10.7, 14.0)	(85.2, 89.1)	(85.9, 89.3)	(10.5, 12.7)	(86.0, 89.2)	(87.3, 89.5)	(-0.4, 1.5)	(-1.5, 0.4)	(-1.5, 0.4)

* Downstream & southward branch: percentage over the entire release particle population. Ratio: particle flux of downstream / (downstream + southward branch)

Table 7-19 Variation Pattern of Particle Fate (45-days' end) with SJR Flow Increasing at SJR Junctions for sjr_omr Scenarios

<table>
<tr><th rowspan="2">Loc</th><th colspan="3">IN</th><th colspan="3">OUT</th><th colspan="3">IN-OUT</th></tr>
<tr><th>branch</th><th>downstream</th><th>ratio</th><th>branch</th><th>downstream</th><th>ratio</th><th>branch</th><th>downstream</th><th>ratio</th></tr>
<tr><td colspan="10">6</td></tr>
<tr><td>HOR</td><td>decrease</td><td rowspan="6">increase</td><td rowspan="4">increase</td><td rowspan="2">mixed</td><td>mixed</td><td rowspan="3">mixed</td><td>negatively increase</td><td rowspan="6">increase</td><td>increase</td></tr>
<tr><td>Turner</td><td rowspan="3">mixed</td><td rowspan="5">increase</td><td>mixed</td><td>mixed</td></tr>
<tr><td>Columbia</td><td>increase</td><td rowspan="3">mixed</td><td>increase</td></tr>
<tr><td>Mmid</td><td>mixed</td><td>increase</td><td>mixed</td></tr>
<tr><td>Rold</td><td>increase</td><td>decrease</td><td>increase</td><td>mixed</td><td>mixed</td></tr>
<tr><td>Jersey</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td colspan="10">21</td></tr>
<tr><td>Turner</td><td rowspan="3">mixed</td><td rowspan="5">increase</td><td>mixed</td><td rowspan="3">mixed</td><td rowspan="5">increase</td><td>mixed</td><td rowspan="2">mixed</td><td rowspan="2">mixed</td><td>mixed</td></tr>
<tr><td>Columbia</td><td rowspan="2">increase</td><td rowspan="2">increase</td><td>mixed</td></tr>
<tr><td>Mmid</td><td>decrease</td><td rowspan="3">increase</td><td>increase</td></tr>
<tr><td>Rold</td><td>increase</td><td>mixed</td><td>increase</td><td>mixed</td><td>increase</td><td>mixed</td></tr>
<tr><td>Jersey</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td colspan="10">351</td></tr>
<tr><td>Jersey</td><td>N/A</td><td>increase</td><td>N/A</td><td>N/A</td><td>increase</td><td>N/A</td><td>N/A</td><td>increase</td><td>N/A</td></tr>
</table>

*Yellow (shaded) cells indicate negative values for most scenarios

Table 7-20 Variation Pattern of Particle Fate (45-days' end) with OMR Increasing at SJR Junctions for sjr_omr Scenarios

<table>
<tr><th rowspan="2">Loc</th><th colspan="3">IN</th><th colspan="3">OUT</th><th colspan="3">IN-OUT</th></tr>
<tr><th>branch</th><th>downstream</th><th>ratio</th><th>branch</th><th>downstream</th><th>ratio</th><th>branch</th><th>downstream</th><th>ratio</th></tr>
<tr><td colspan="10">6</td></tr>
<tr><td>HOR</td><td rowspan="3">increase</td><td rowspan="6">decrease</td><td rowspan="4">decrease</td><td>increase</td><td rowspan="6">decrease</td><td>decrease</td><td>negative increase</td><td>increase</td><td>increase</td></tr>
<tr><td>Turner</td><td rowspan="3">mixed</td><td>mixed</td><td rowspan="2">increase</td><td>mixed</td><td rowspan="4">mixed</td></tr>
<tr><td>Columbia</td><td rowspan="2">decrease</td><td rowspan="4">decrease</td></tr>
<tr><td>Mmid</td><td>mixed</td><td>mixed</td></tr>
<tr><td>Rold</td><td>decrease</td><td>mixed</td><td>decrease</td><td>mixed</td><td>decrease</td></tr>
<tr><td>Jersey</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td colspan="10">21</td></tr>
<tr><td>Turner</td><td rowspan="2">increase</td><td>mixed</td><td rowspan="3">decrease</td><td rowspan="3">mixed</td><td>mixed</td><td>mixed</td><td rowspan="3">mixed</td><td>mixed</td><td>mixed</td></tr>
<tr><td>Columbia</td><td rowspan="4">decrease</td><td rowspan="4">decrease</td><td rowspan="2">decrease</td><td rowspan="3">mixed</td><td>increase</td></tr>
<tr><td>Mmid</td><td>mixed</td><td>mixed</td></tr>
<tr><td>Rold</td><td>decrease</td><td>mixed</td><td>decrease</td><td>mixed</td><td>mixed</td><td>mixed</td></tr>
<tr><td>Jersey</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td><td>decrease</td><td>N/A</td></tr>
<tr><td colspan="10">351</td></tr>
<tr><td>Jersey</td><td>N/A</td><td>decrease</td><td>N/A</td><td>N/A</td><td>decrease</td><td>N/A</td><td>N/A</td><td>increase</td><td>N/A</td></tr>
</table>

*Yellow cells indicate negative values for most scenarios

7.6 Conclusions

This study provides a sensitivity investigation on the movement of neutrally buoyant particles due to variations of San Joaquin River inflow, Jones and Banks exports, and the Head of Old River barrier, in the Sacramento-San Joaquin Delta during the spring season. Simulation results created a Delta hydrodynamic database for better understanding the boundary inputs' effects.

Although different particle insertions and output retrieval locations affect the results substantially, some general variation patterns could be found:

- Higher SJR inflows and smaller OMR (higher export) carry more particles to Martinez and less to CVP/SWP exports, which usually corresponds to SJR junctions split pattern of more flux to mainstem downstream. SJR flow usually has dominant contribution at its high flow level.
- HORB's effect depends on insertion locations, boundary inputs, and adaptive management selection (sjr_ie or sjr_omr).
- The scenarios simulation result matrix could be used to obtain the detailed variation patterns and ranges, which are helpful in understanding different variables' contributions.
- Insertion locations play a key role in particle behaviors' change under the effect of other boundary/facility operations. Locations farther from Chipps, especially upstream of HOR could have very different (even opposite) patterns from downstream or locations very close to Chipps.

For detailed simulation configuration and result data files and plots, please refer to the website: https://msb.water.ca.gov/delta-modeling/-/document_library/view/95707

7.7 Acknowledgments

We thank Yu Min and Xiaochun Wang for their helps in report revisions, Kijin Nam and Prabhjot Sandhu for their help in quality checks.

7.8 References

Division of Operations and Maintenance. (1989). Standing Operating Order PC 200.7-A. Sacramento: California Department of Water Resources.

Le, K. (2004). Calculating Clifton Court Forebay Inflow (Chapter 12). In *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh, 22nd Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources, Bay-Delta Office, Delta Modeling Section.

Appendixes A-1 through D-6

Note: All appendixes are stored in DWR Bay-Delta Office DSM2 User Group website.

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/

The following links are accesses to the each appendix respectively.

Appendix A-1: Sacramento Sensitivity Test for Particle insertion at Mossdale (node 6) HORB-IN

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/A1_sac_6_IN.docx

Appendix A-2: Sacramento Sensitivity Test for Particle insertion at Mossdale (node 6) HORB-OUT

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/A2_sac_6_OUT.docx

Appendix A-3: Sacramento Sensitivity Test for Particle insertion at Calaveras (node 21) HORB-IN

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/A3_sac_21_IN.docx

Appendix A-4: Sacramento Sensitivity Test for Particle insertion at Calaveras (node 21) HORB-OUT

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/A4_sac_21_OUT.docx

Appendix A-5: Sacramento Sensitivity Test for Particle insertion at Rio Vista (node 351) HORB-IN

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/A5_sac_351_IN.docx

Appendix A-6: Sacramento Sensitivity Test for Particle insertion at Rio Vista (node 351) HORB-OUT

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/A6_sac_351_OUT.docx

Appendix B-1: OMR over time of SJR_IE Scenarios

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/B1_OMR_sjr_ie.docx

Appendix B-2: OMR over time of SJR_OMR Scenarios

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/B2_OMR_sjr_omr.docx

Appendix B-3: SJR junctions split of average flow over 45-days of SJR_IE Scenarios

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/B3_SD_sjr_ie.docx

Appendix B-4: SJR junctions split of average flow over 45-days of SJR_OMR Scenarios by OMR sequence

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/B4_SD_sjr_omr.docx

Appendix B-5: SJR junctions split of average flow over 45-days of SJR_OMR Scenarios by SJR sequence

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/B5_SD_sjr_omr_by_sjr.docx

Appendix C-1: Standard particle flux fates at 45-days' end of SJR_IE Scenarios

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/C1_PTM_sjr_ie_std.docx

Appendix C-2: Standard particle flux fates at 45-days' end of SJR_OMR Scenarios by OMR sequence

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/C2_PTM_sjr_omr_std.docx

Appendix C-3: Standard particle flux fates at 45-days' end of SJR_OMR Scenarios by SJR sequence

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/C3_PTM_sjr_omr_std_by_sjr.docx

Appendix D-1: SJR junctions split of particle flux fates (%) at 45-days' end of SJR_IE Scenarios

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/D1_PTM_sjr_ie_sd.docx

Appendix D-2: SJR junctions split ratio of particle flux fates at 45-days' end of SJR_IE Scenarios

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/D2_PTM_sjr_ie_sd_ratio.docx

Appendix D-3: SJR junctions split of particle flux fates (%) at 45-days' end of SJR_OMR Scenarios by OMR sequence

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/D3_PTM_sjr_omr_sd.docx

Appendix D-4: SJR junctions split ratio of particle flux fates at 45-days' end of SJR_OMR Scenarios by OMR sequence

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/D4_PTM_sjr_omr_sd_ratio.docx

Appendix D-5: SJR junctions split of particle flux fates (%) at 45-days' end of SJR_OMR Scenarios by SJR sequence

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/D5_PTM_sjr_omr_sd_by_sjr.docx

Appendix D-6: SJR junctions split ratio of particle flux fates at 45-days' end of SJR_OMR Scenarios by OMR sequence

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_NMFS/D6_PTM_sjr_omr_sd_ratio_by_sjr.docx