

***RMA***

**RESOURCE MANAGEMENT ASSOCIATES, INC.  
FAIRFIELD, CALIFORNIA**

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**Technical Memo:  
Initial Modeling of Levee Breaches**

**Prepared for:  
Delta Levees Risk Assessment Team**

**January 2004**

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Prepared by  
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## **1 OBJECTIVES**

The objective of the initial modeling is to provide insight to the Delta Levees Risk Assessment Team (LRAT) to the consequences of possible levee failures and aid in the development of the work plan. The modeling includes the impact of the initial flooding of islands following a breach, evolution of the salinity field as the breach is stabilized and repaired, and the recovery period while salinity levels fall back to the point where exports may be resumed. The critical product of the hydrodynamic and salinity modeling is how long it takes for export operations to be resumed.

The full risk assessment will likely require consideration of breaches occurring during different water years, seasons, and points in the spring-neap tidal cycle as well as different operational responses (reservoir releases and control structure operation) depending on the breach configuration. For the initial modeling, a single dry year condition has been simulated for several breach cases. The effort spent setting up the initial runs will be directly useful in preparing for the full risk assessment modeling.

## **2 RMABAY DELTA MODEL**

Resource Management Associates (RMA) has developed and maintains a numerical model of the San Francisco Bay and Sacramento-San Joaquin Delta (Figure 1), which extends from the Golden Gate inland to the confluence of the American and Sacramento Rivers, and to Vernalis on the San Joaquin River. The model is based on the RMA suite of multi-dimensional finite element

models for surface water systems. The hydrodynamic model RMA2 is used to solve the shallow water equations for conservation of fluid mass and momentum in two-dimension depth-averaged and one-dimensional cross-sectionally averaged elements. The water quality transport model RMA11 is used to solve the mass transport equation based on the velocity field provided by the RMA2 model.

San Francisco Bay and Suisun Bay regions, the Sacramento-San Joaquin confluence area, Frank's Tract and the Delta Cross Channel area are represented using a two-dimensional depth-averaged approximation, and Delta channels and tributary streams are represented using a one-dimensional cross-sectionally averaged approximation. Model resolution (number, size, and shape of computational elements) has been developed to best represent changes in bottom elevation while maintaining reasonable speed of computation. Additional detail is added where there are strong hydraulic or water quality gradients such as near hydraulic control structures and treated wastewater outfalls. The Bay-Delta network was developed using a GIS based graphical user interface program. The program allows for development 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 south of Dumbarton Bridge. Bottom elevations and the extent of mudflats were based on NOAA navigation charts, and bathymetry data collected by NOAA, DWR and USGS.

Hydrodynamic model operation requires specification of the tidal stage at the Golden Gate and inflow and withdrawal rates at other external boundaries. Inflows include Sacramento River, San Joaquin Rivers and other rim flows, channel depletions, exports (SWP, CVP, Contra Costa Canal, and North Bay Aqueduct), and municipal and industrial wastewater sources.

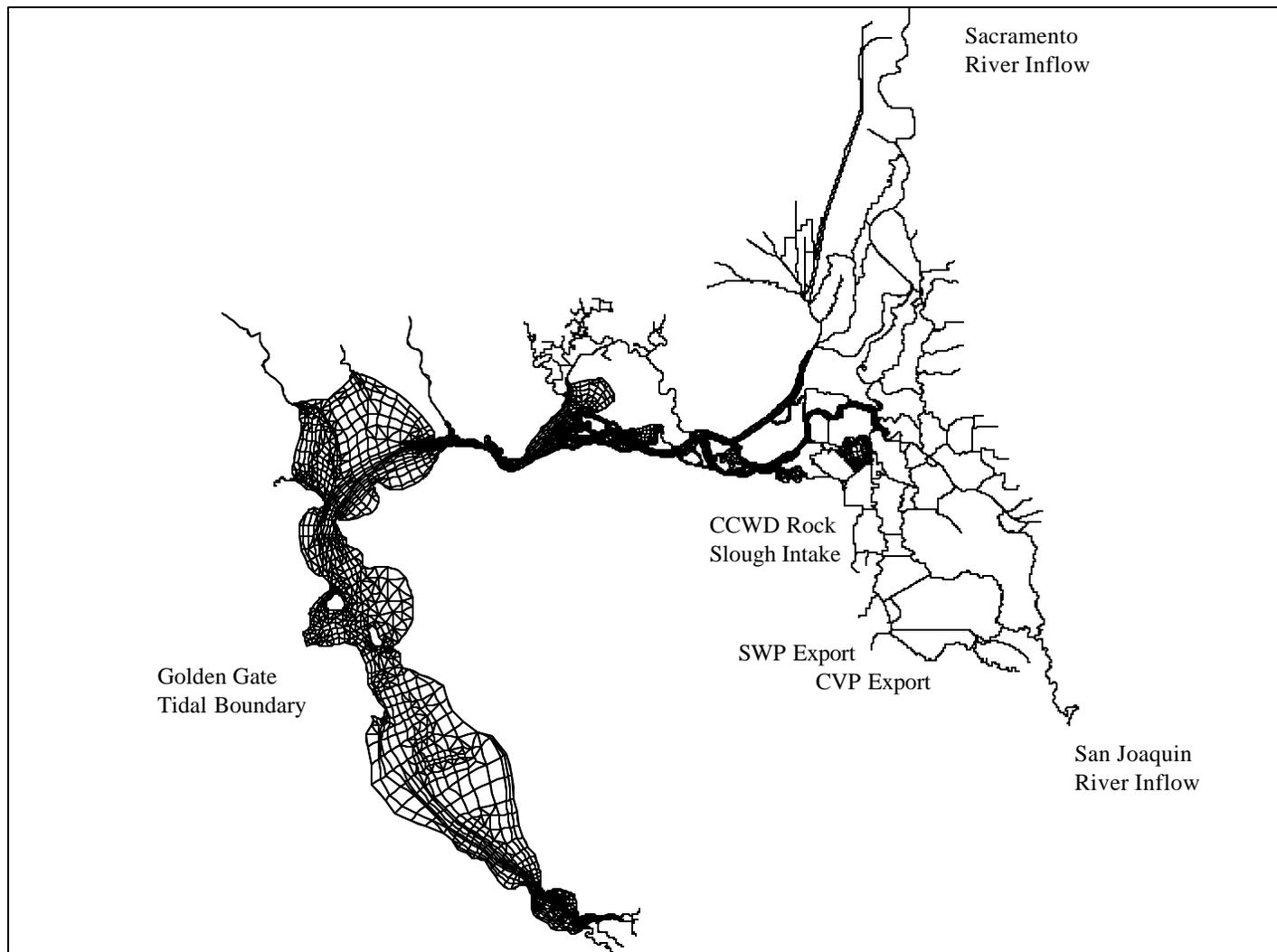
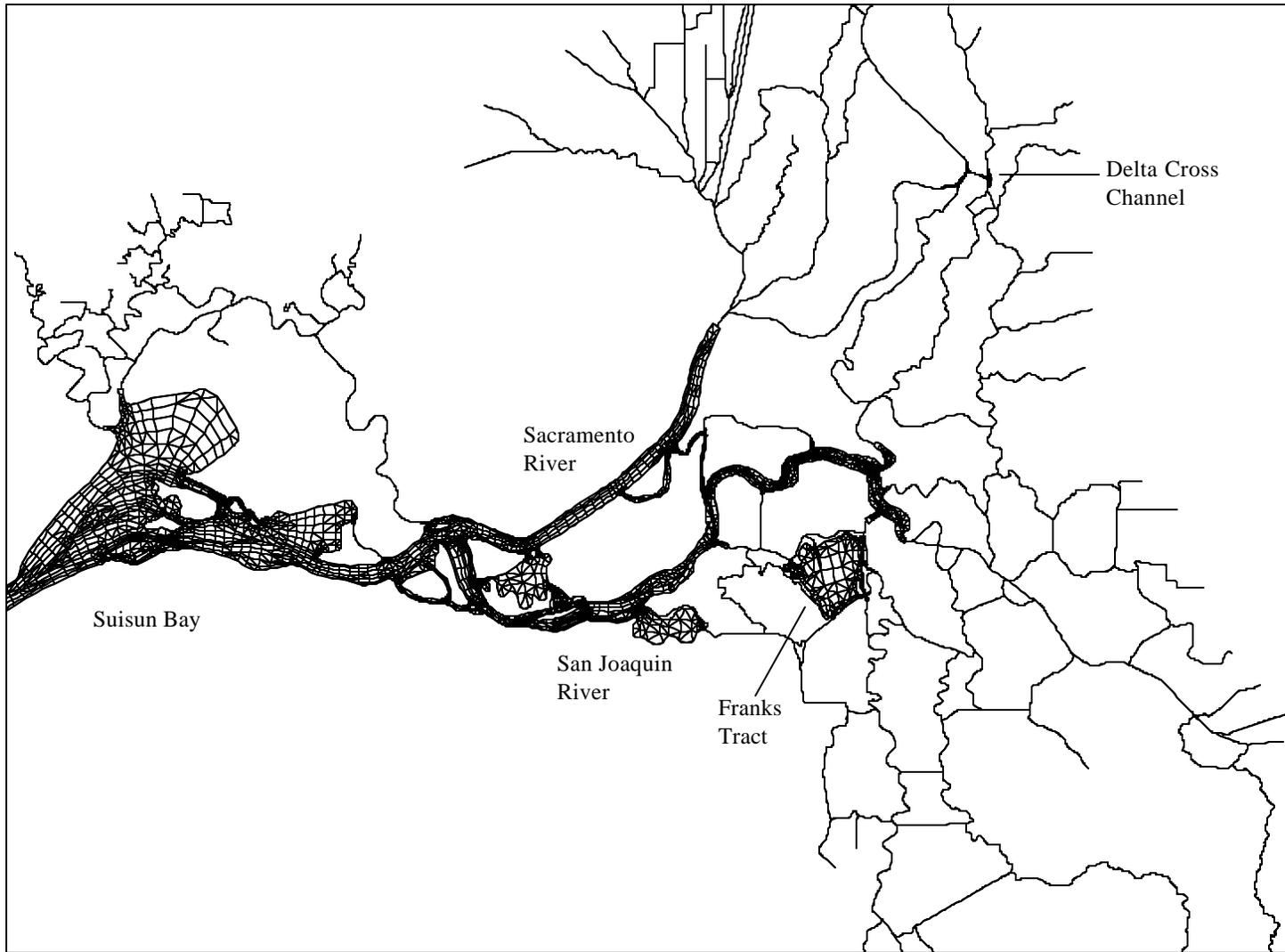


Figure 2-1 RMA Bay-Delta model.



**Figure 2-2 RMA Bay-Delta model (close-up of Suisun Bay and Central Delta).**

### 3 EVALUATION CASE

Historic conditions from July 1992 through January 1993 were selected as the evaluation case for the initial levee breach modeling. This period represents a near worst case condition as it was the last in a series of dry years and the net Delta outflow was very low through the late summer and fall. Net Delta outflow increases sufficiently in January 1993 to flush the Delta. Details of the evaluation case are as follows.

**Simulation Period:** July 1992 through January 1993. Breaches occur on July 1 and the simulations continue through the end of January when wet weather flows return.

**Tide:** The historic Golden Gate tide was used throughout the simulation (Figure 3-1).

**Hydrology:** Delta rim flows were based on historic daily average values from the Interagency Ecological Program (IEP) DayFlow database. No additional releases were made to improve flushing of salinity after breach events (Figure 3-2).

**Control Structures:** Historic 1992 operations were used for the Cross Channel, Montezuma Slough Salinity Control Structure, and South Delta Barriers. Because the full risk assessment will need to consider the current Delta control structures, the new barrier on Grantline Canal was included in the evaluation case even though it was not actually operational in 1992.

**Exports:** Two cases were simulated. The base condition used historic values from the DayFlow database for all Delta exports (Figure 3-3). A second case was run with Contra Costa Water District at Rock Slough (CCWD), Central Valley Project (CVP), and State Water Project (SWP) exports set to zero on July 1<sup>st</sup> and remaining at zero for the duration of the simulation.

**DICU:**

Delta Island Consumptive Use was based on DWR's estimates of the historic monthly average diversion and returns (Table 3-1). The RMA Bay Delta Model distributes the DICU flows throughout the Delta according to DWR's data, but the diversions and seepage (which remove water from the Delta channels) are combined with the drain flow (which returns water to the Delta). When the total DICU flow (diversion + seepage – drain) is negative indicating a net return flow, it is returned at ambient salinity levels. This assumption can lead to an underestimation of salinity in the summer, and an over estimation of salinity in the winter as local precipitation is included in the drain flow. There is considerable uncertainty in the best estimate of the DICU so RMA has not yet concentrated on improving the representation of DICU in the model. However, since winter flushing of salinity in the south Delta may be an important aspect of the risk analysis it may be necessary to update the model to consider the salinity impact of return flows.

**Table 3-1 Total monthly average Delta diversions and return flows.**

	<b>Diversions (cfs)</b>	<b>Drains (cfs)</b>	<b>Seepage (cfs)</b>	<b>Total (cfs)</b>
Jul-92	5263	2106.4	973	4129.6
Aug-92	3404.4	1497.7	973	2879.7
Sep-92	1489.6	925.6	1006	1569.9
Oct-92	532	587.3	982.2	927
Nov-92	446.8	549.7	1008.4	905.6
Dec-92	429.2	1290.9	719.8	-141.9
Jan-93	0	6875.4	496.5	-6378.9



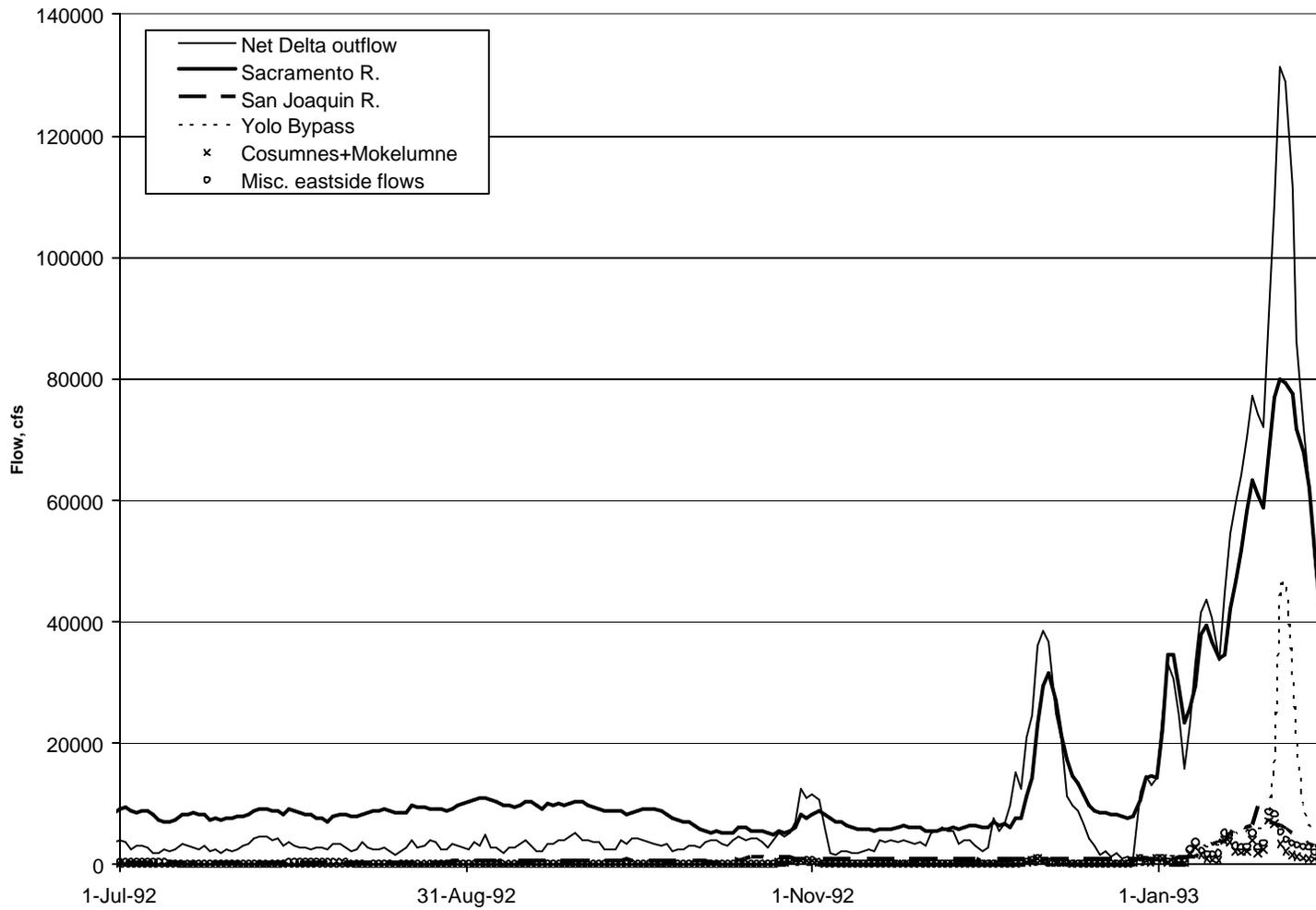


Figure 3-2 Net Delta outflow and river inflows (IEP Dayflow).

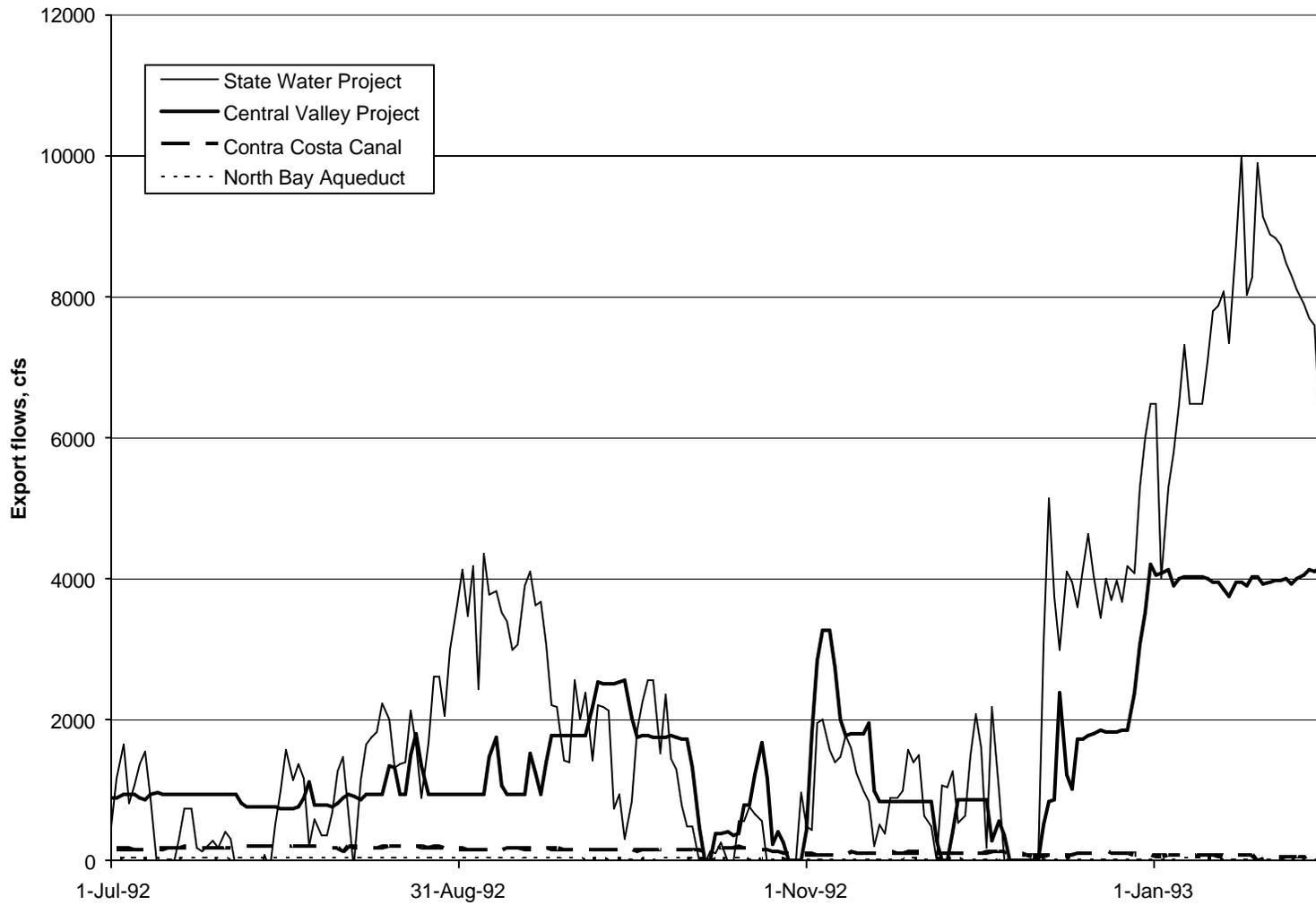


Figure 3-3 Export flows (IEP Dayflow).

## 4 BREACH CONFIGURATIONS

Model configurations were developed to represent breaches on three Delta islands including

- the north west levee of Sherman Island on the Sacramento River,
- the south levee of Andrus Island on the San Joaquin River, and
- the west levee of Bacon Island on Old River.

Model geometry for the breach configurations are shown in Figures 4-1 through 4-4. For the initial modeling the islands were given flat bottoms approximating the actual island topography. For the actual risk assessment modeling, the islands will be made to more closely represent the actual topography.

Breach simulations were performed for all islands individually and the three islands together where export pumping ceased at the time of the breach. One additional simulation was performed where export pumping continued at historic levels for the duration of the simulation.

Breaches occurred over a 24 hour period, growing to a width of 350 to 750 feet and a depth of approximately -25 to -35 ft MSL. The breaches remained open through the month of July. For the individual cases the breach was closed over a 24 hour period at the beginning of August. For the three island case, the Sherman Island breach was repaired at the beginning of August. The Andrus Island breach was repaired on the 15<sup>th</sup> of August. And the Bacon Island breach was repaired at the beginning of September.

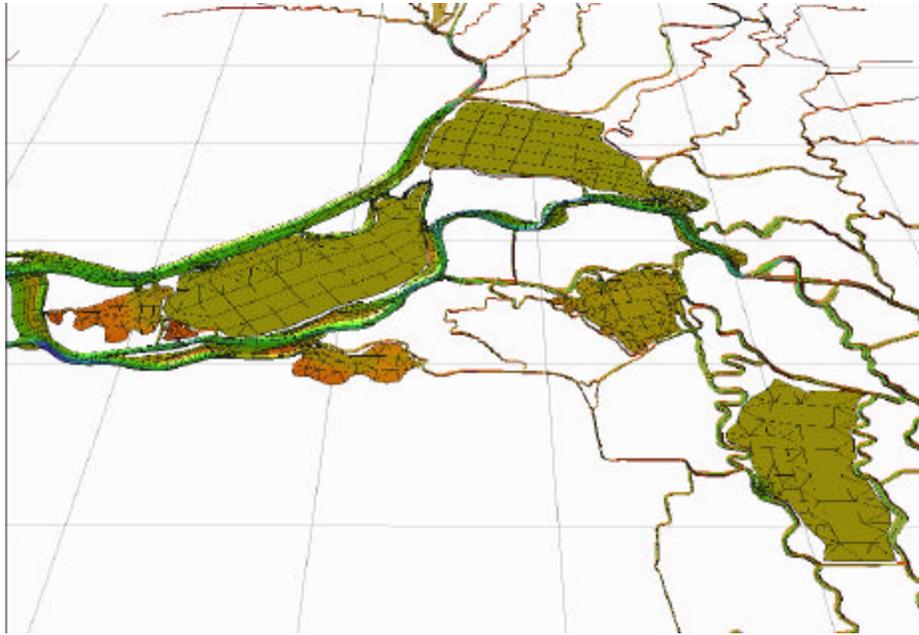


Figure 4-1 Model geometry with Sherman, Andrus and Bacon Island levee breaches.

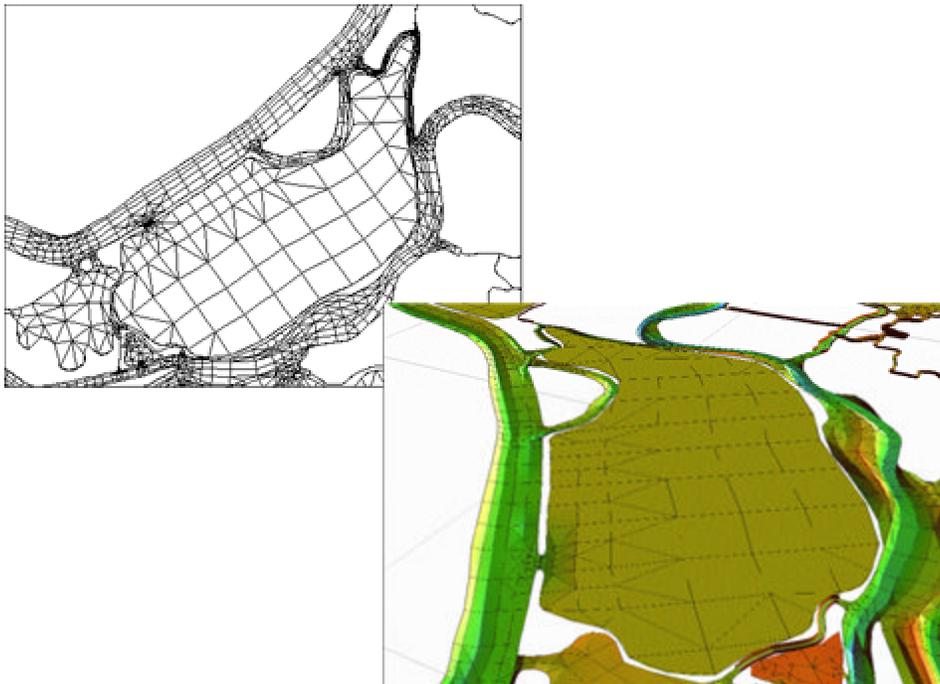


Figure 4-2 Sherman Island breach geometry.

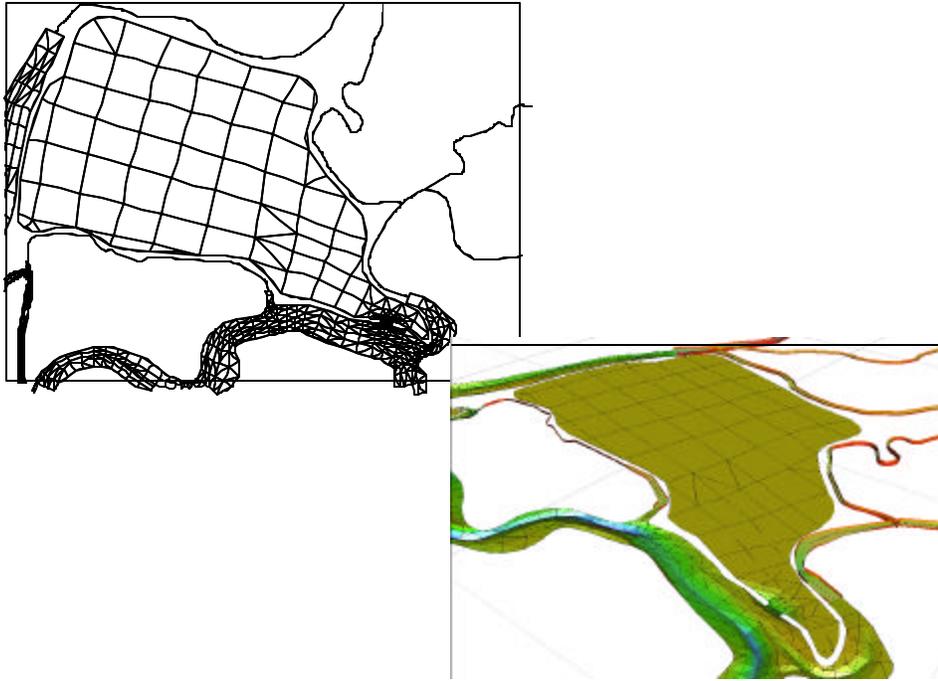


Figure 4-3 Andrus Island breach geometry.

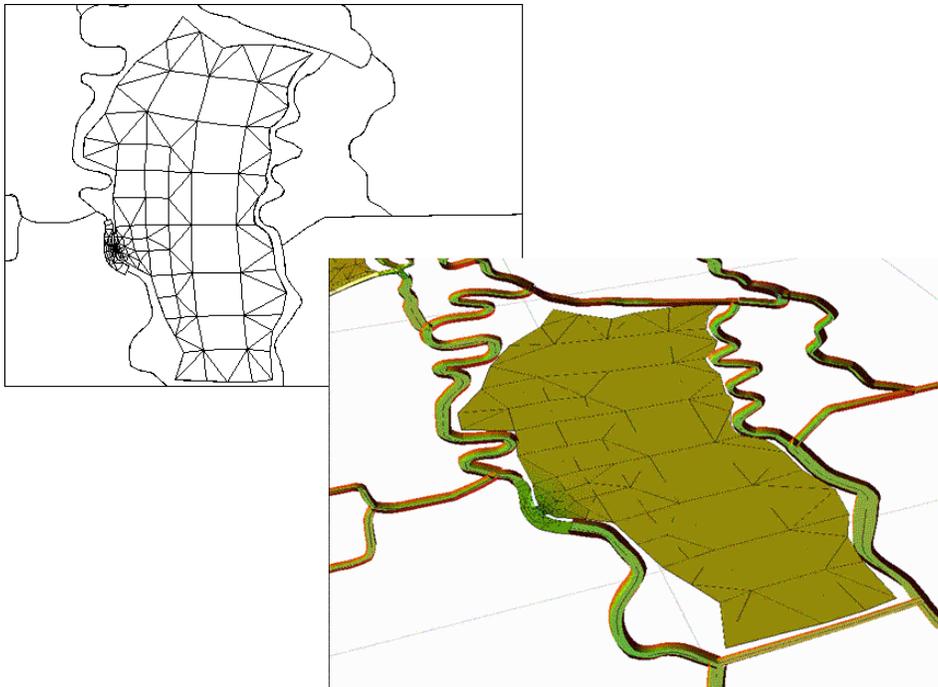


Figure 4-4 Bacon Island breach geometry.

## **5 MODEL RESULTS**

### **5.1 EVALUATION CASE WITH AND WITHOUT EXPORT PUMPING**

The amount of fresh water flowing through the Delta toward San Francisco Bay, or Net Delta Outflow, plays a critical role in establishing the salinity levels in the Suisun Bay and the Delta.

During the summer and fall Delta exports and upstream reservoir releases are balanced to meet specific water quality objectives by managing the Net Delta Outflow. When exports are stopped without reducing upstream reservoir releases, the Net Delta Outflow increases, acting to freshen the central and western Delta. Figure 5-1 shows the percent difference between the with and without export pumping simulations on September 30, 1992.

Without export pumping, the circulation in the southern Delta is greatly reduced. Any build up of salt that occurs during the summer and fall will not be flushed as quickly when wet weather flows coming down the Sacramento River freshen the central Delta. There will also be more influence of the San Joaquin River salinity.

### **5.2 GENERAL IMPACT OF LEVEE BREACHES ON DELTA SALINITY**

There is an immediate salinity impact following a breach event when higher salinity water from Suisun Bay is drawn into the Delta as the island floods. The amount of Suisun Bay water pulled into the Delta depends both on the volume of the island breached and the proximity of the breach to Suisun Bay. Figure 5-2 shows the immediate impact of island flooding for the three breach case relative to the “without export pumping” simulation. Note that the salinity impact extends all the way to San Pablo Bay.

As long as the breach remains open, daily filling and draining of the island with the tide changes the mixing characteristics of the Delta, which in most cases will increase salinity levels over time. The flooded island can increase mixing by increasing the tidal excursion in channels throughout the neighborhood of the breach and by tidal trapping of salt as water flows in and out

of the breach itself (Figure 5-3). The impact of a levee breach on mixing of salinity in the Delta depends strongly on the location of the breach as well as the active tidal prism of the flooded island. Breaches located on large channels nearer Suisun Bay will have a much greater impact than breaches on smaller channels farther inland. Figure 5-4 shows salinity profiles from the Golden Gate to Rio Vista on the Sacramento River for all of the model runs.

Higher salinity in the western and central Delta will, over time, lead to increased salinity in the southern Delta. This process is very rapid if export pumping continues following a levee breach, but even if pumping is stopped salt will slowly diffuse into the southern Delta. Once levee breaches are repaired, salinity in the central and western Delta will recover fairly quickly, but the higher salinity water will tend to remain in the southern Delta until it is flushed by pumping or wet weather inflows.

This behavior is illustrated in Figures 5-5 through 5-11 which show color contours of the salinity difference in percent between the three breach case and the base case without export pumping at monthly intervals from July through January.

### **5.3 COMPARISON OF SALINITY TIME SERIES AT KEY LOCATIONS**

Time series of the tidally averaged (24.5 hour running average) salinity are shown in Figures 5-12 through 5-16 for five key locations:

- Sacramento River at Collinsville,
- Old River just south of Franks Tract,
- Rock Slough near the Contra Costa Water District Intake,
- Old River at the State Water Project Intake, and
- Central Valley Project Intake.

#### **5.3.1 Collinsville**

The base runs with and without exports begin to diverge immediately. The difference between these two runs increases over about three months and stabilizes with the base run with

exports about 3 ppt higher than the without exports run. This difference remains until wet weather flows occur in mid December.

The impact of island flooding is evident at the beginning of July. There is approximately a 0.8 ppt increase in salinity for the Bacon Island breach, 2.25 ppt increase for Sherman and Andrus Island Breaches, and a 6.5 ppt increase for the three breach case.

For the breach cases without exports, salinity declines once the breaches are repaired, reaching the base without export condition by October before wet weather flows arrive.

The three breach case with exports remains at a higher salinity and the base with export condition slowly increases to match it. By the end of October, influence of the breaches has diminished and the with and without export simulations stabilize with a salinity difference that is a function of the Net Delta Outflow.

### **5.3.2 Old River south of Franks Tract**

Salinity of the base run with exports rises to about 0.6 ppt in September then is brought back and “managed” at 0.45 ppt in November and December as the reservoir releases are balanced with south Delta exports to maintain water quality at the SWP and CVP pumps. When the storm flows come in mid December the salinity drops off. Salinity of the base without exports run is stable at 0.25 ppt throughout most of the eight month simulation. Only at the very end of the simulation does the salinity start to increase. This is due to the influence of higher salinity inflows to the San Joaquin River slowly making its way north through the Delta.

Salinity increases related to the initial island flooding are evident, but not as pronounced as at Collinsville. Salinity increases are more a function of the increased tidal mixing while the breaches are open.

The Bacon Island breach has negligible impact on salinity and at times slightly reduces the salinity. The Sherman and Andrus Island breaches show similar salinity increase of about 0.15 ppt relative to the base without export case. The Andrus Island breach shows a greater impact of the initial flooding (the salinity rises sooner and recovers sooner) while the Sherman Island breach shows greater impact of increased tidal mixing (salinity rises more slowly and persists

longer). The three breach case without exports has an increase of 0.63 ppt over the base without exports case, which is significantly larger than the sum of the increases for the three individual breach cases. The three breach case with exports has a much higher impact still with a 1.1 ppt increase over the base case with imports. Once the breaches are repaired the salinities return toward their base conditions slowly. The three breach case without exports does not recover even at the end of eight months – this is because the salt stored in the south delta is very slow to wash out. Note that for the cases with export pumping, salinities begin to decrease rapidly in late November as fresher water is drawn into the south Delta by the pumps. Without export pumping, salinities increase in the last month of the simulation as a result of a pulse of relatively higher salinity from the San Joaquin River boundary.

### **5.3.3 CCWD, SWP and CVP intakes**

The time series of salinity at the three intakes are similar so they are presented together.

Without export pumping, the impact of the initial island flooding is not evident. Salinity increases slowly as tidal mixing draws salt southward from the central Delta. The individual breach cases do not exceed the base with export case until winter when higher salinity San Joaquin water finally reaches the export locations. At the SWP location, the salinity falls off in January because there is a spike of low salinity water that comes down the San Joaquin River and reaches the SWP first via Grant Line Canal. That influence is only just being felt at the other intake locations at the very end of the simulation.

For the three breach case without exports, salinity reaches approximately 0.6 ppt then drops below the 0.5 ppt threshold in November.

The three breach case with exports shows an initial dramatic increase in salinity to over 1.1 ppt as high salinity water in the central Delta is quickly drawn to the pumps. As the salinity washes out of the central Delta toward the end of November, the salinity at the exports is lower than the other breach cases because fresher water is being drawn south by the exports.

Note that at the SWP and CVP pumps the base case with export pumping reflects the management of reservoir releases and pumping so that the exports remain below 0.5 ppt.

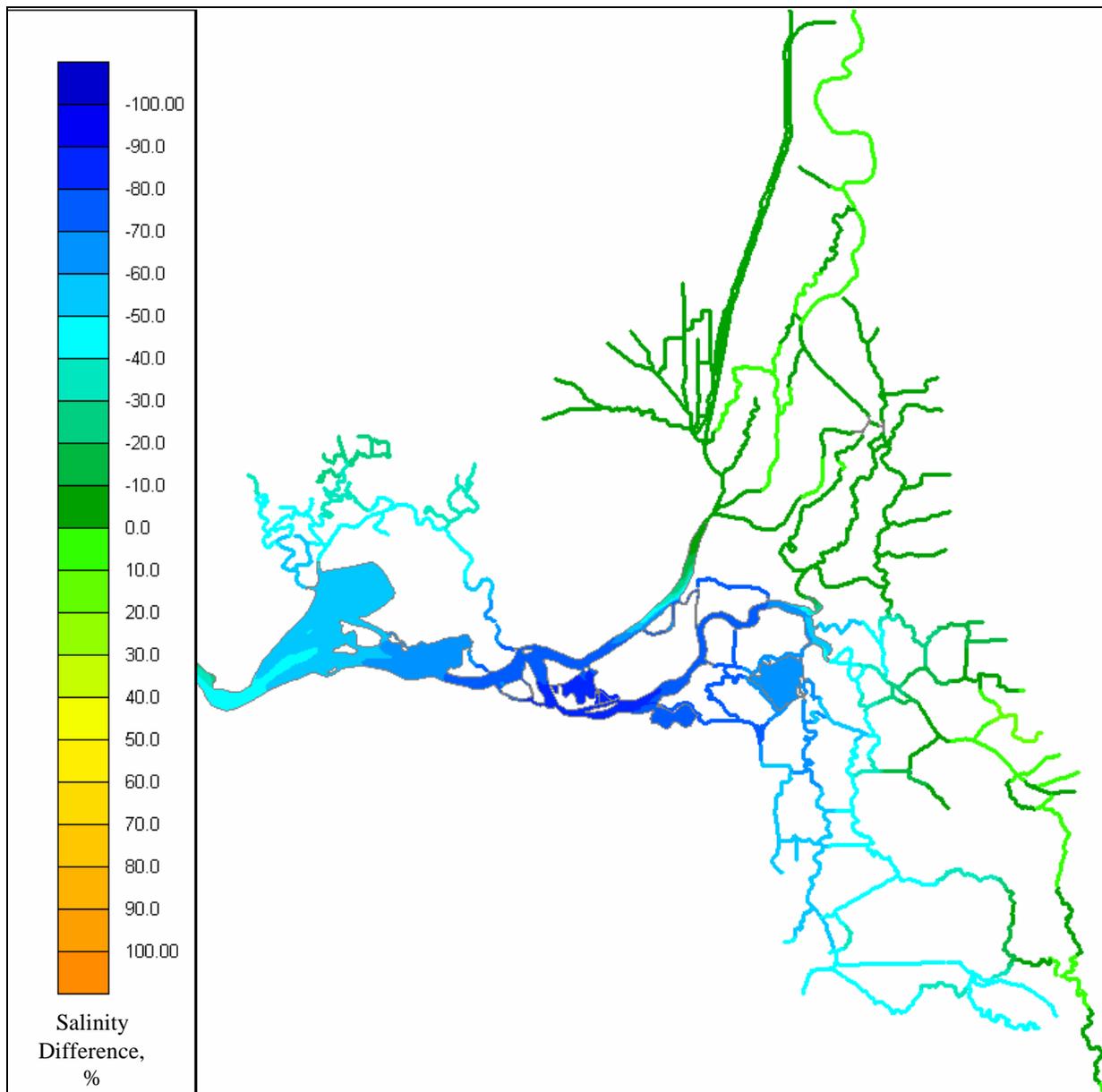


Figure 5-1 Salinity difference in percent between “with exports” and “without exports” simulations on September 30, 1992.

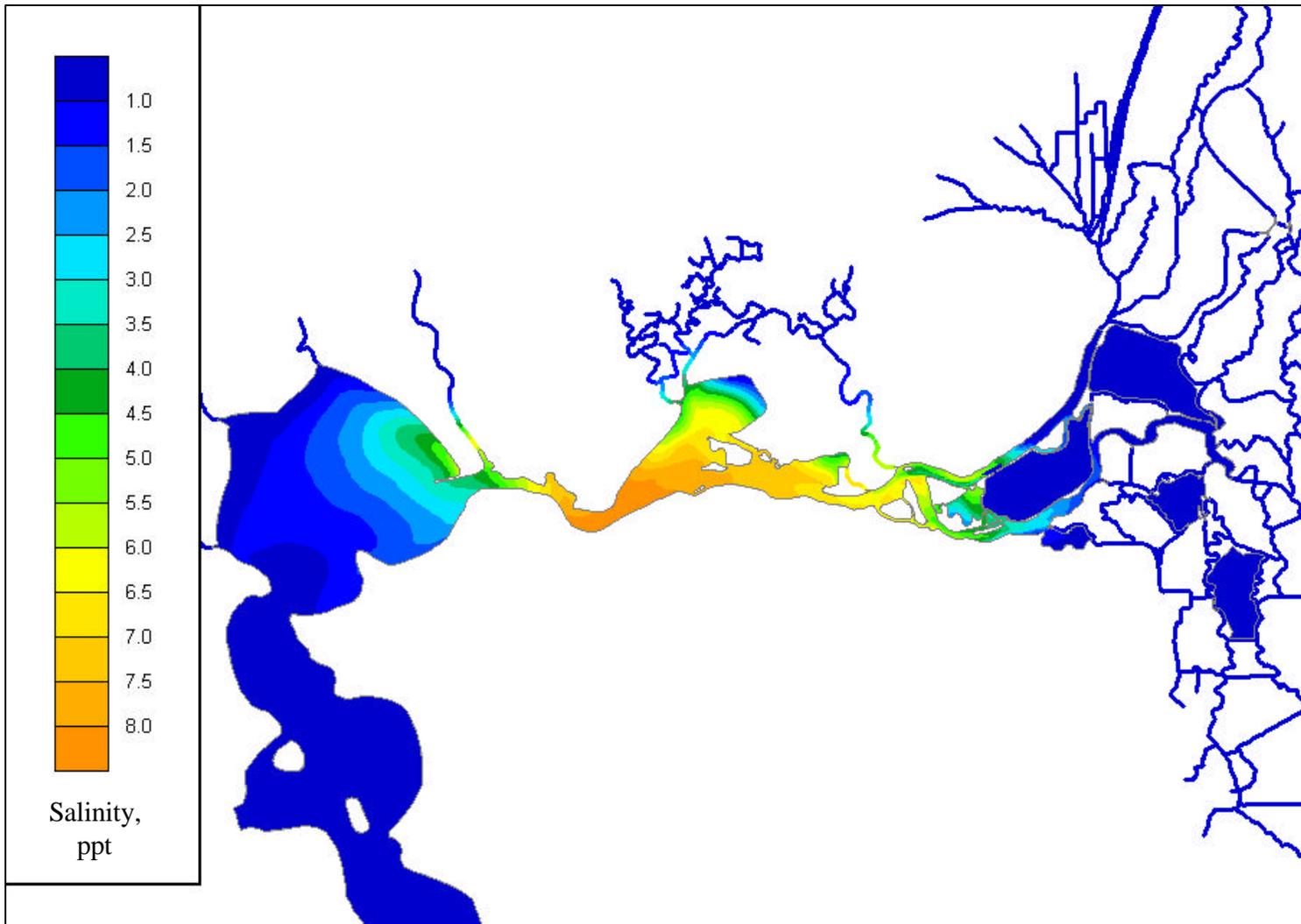


Figure 5-2 Salinity difference (ppt) for three breach case vs. base without exports on July 3.

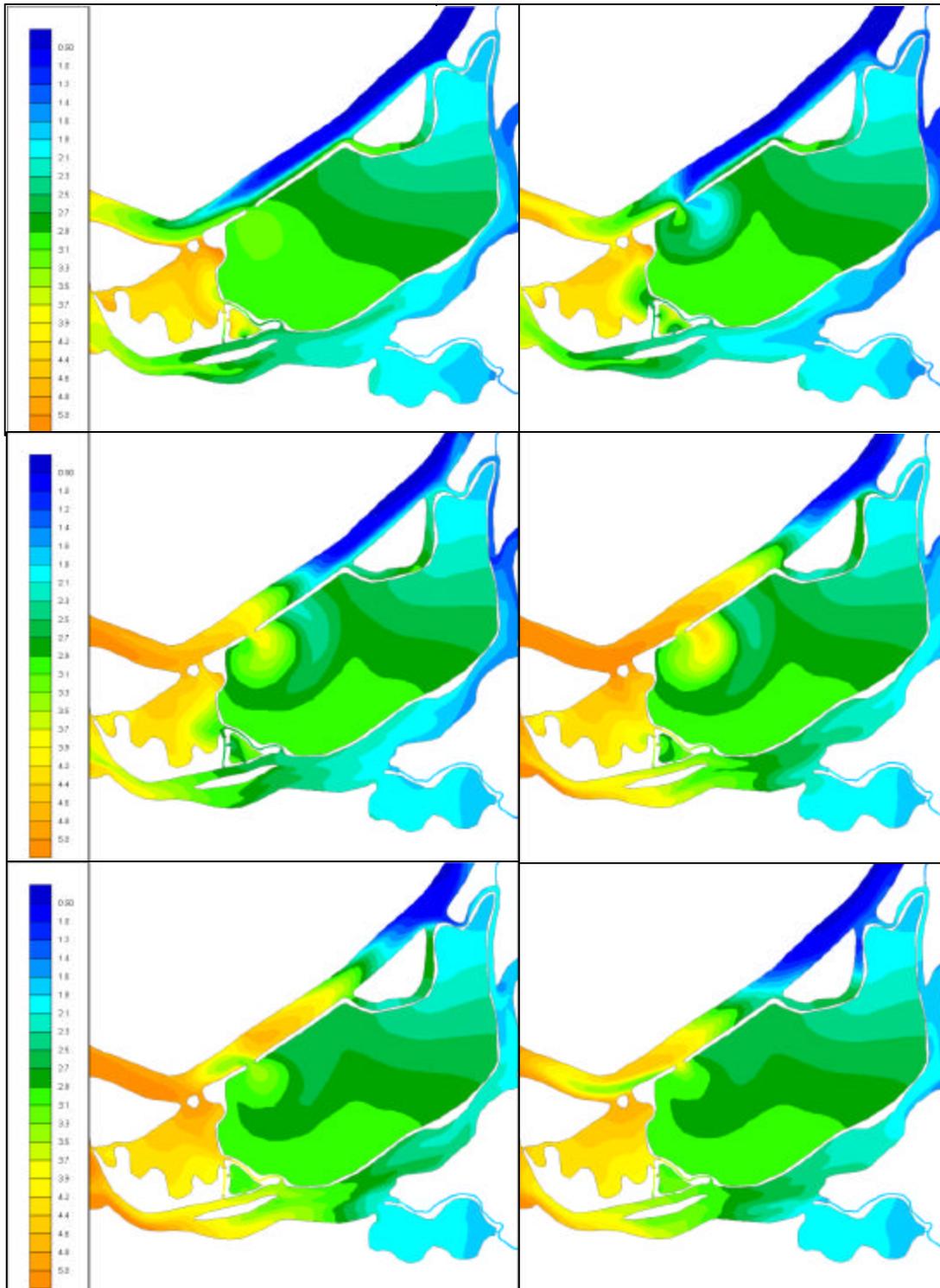


Figure 5-3 Salinity concentration contours (ppt) at 2 hour intervals following breach of Sherman Island levee.

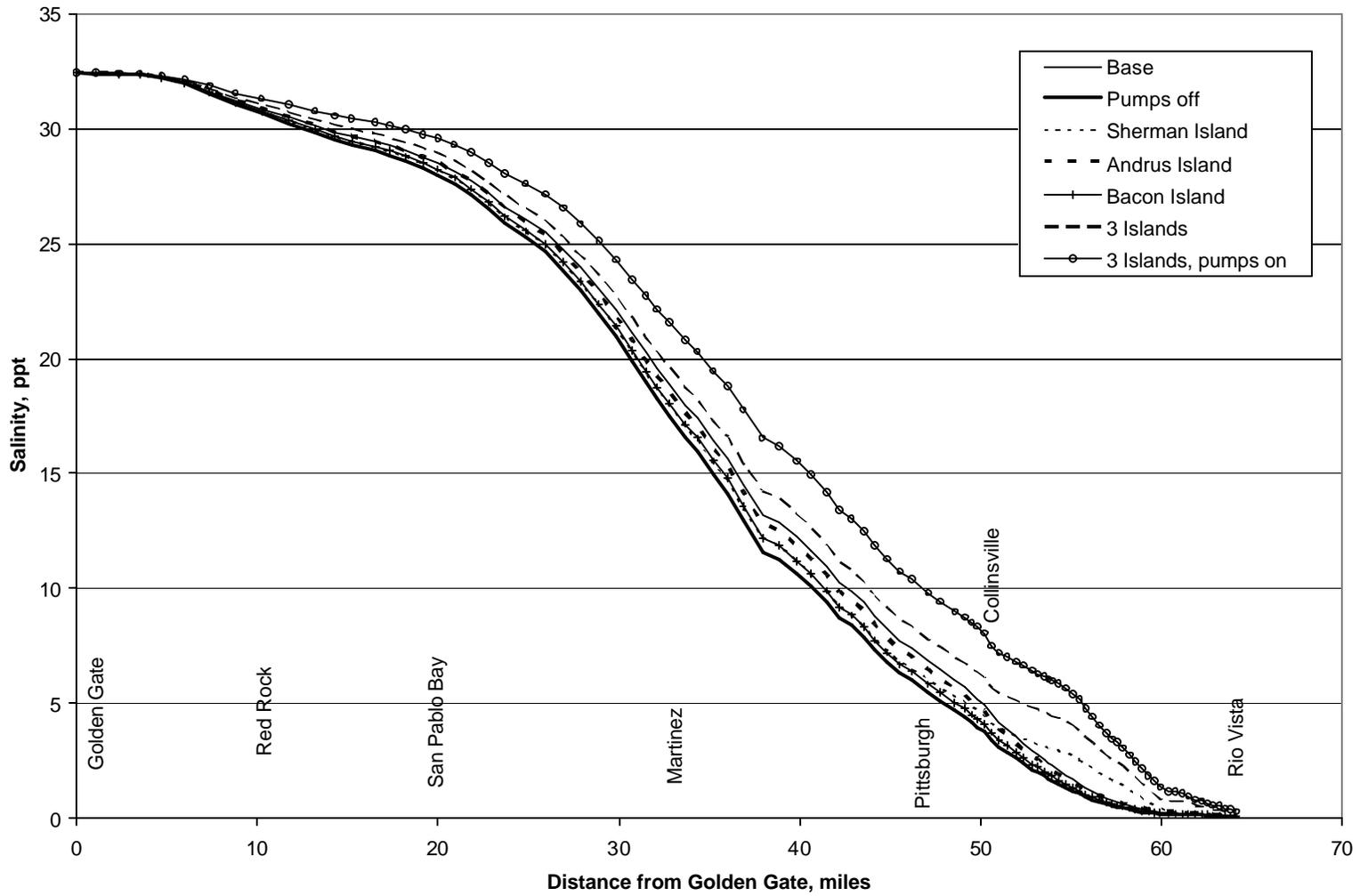


Figure 5-4 Profile of tidally averaged salinity from Golden Gate to Rio Vista on August 1.

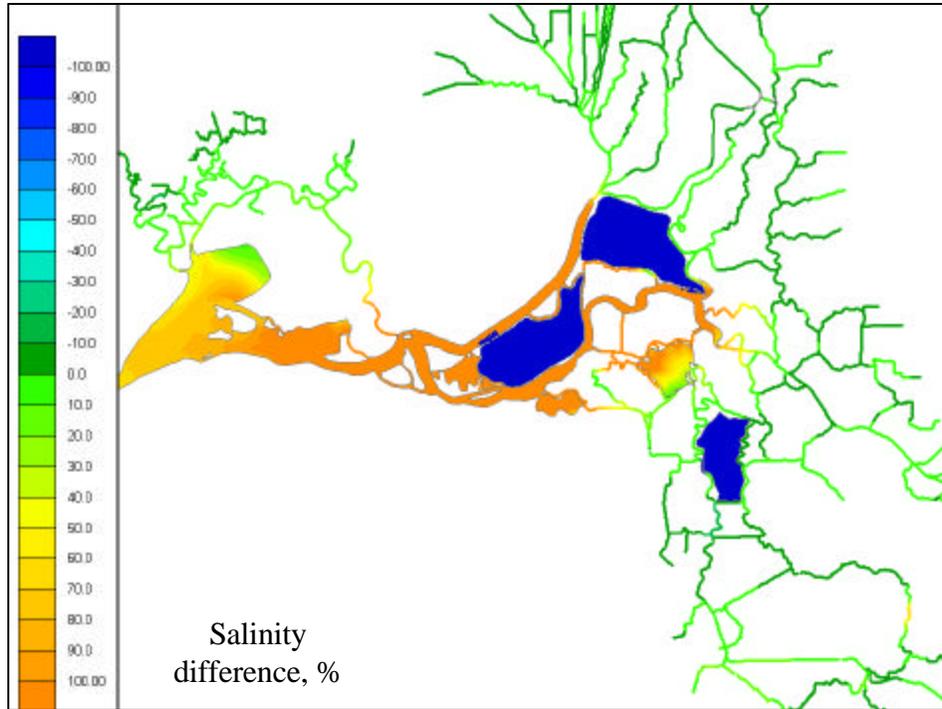


Figure 5-5 Salinity difference (%) for three breach case vs. base without exports, July 3.

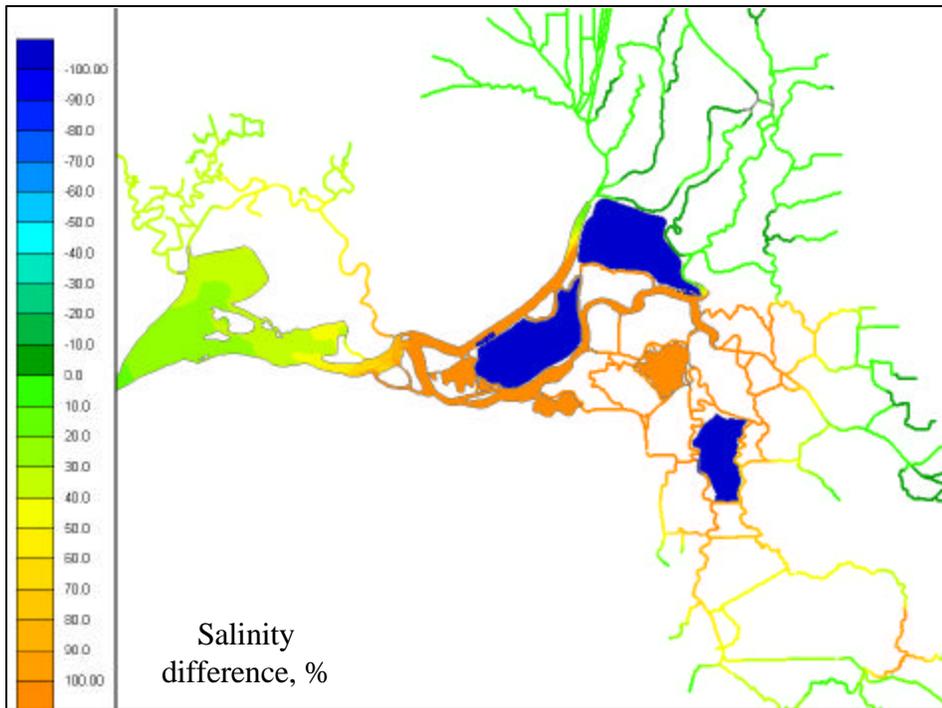


Figure 5-6 Salinity difference (%) for three breach case vs. base without exports, August 1.

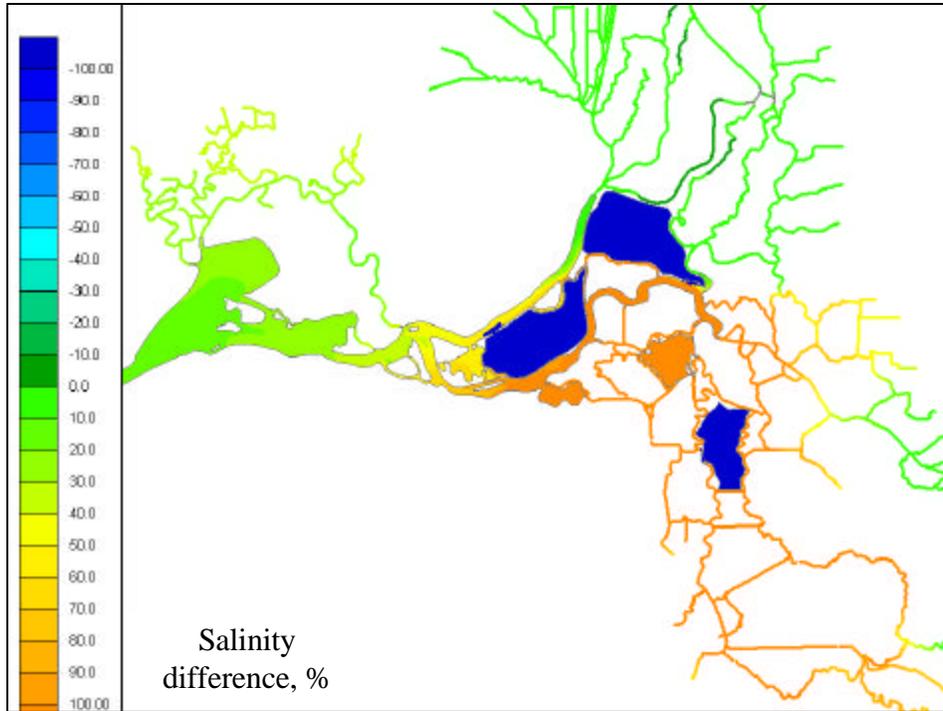


Figure 5-7 Salinity difference (%) for three breach case vs. base without exports, September 1.

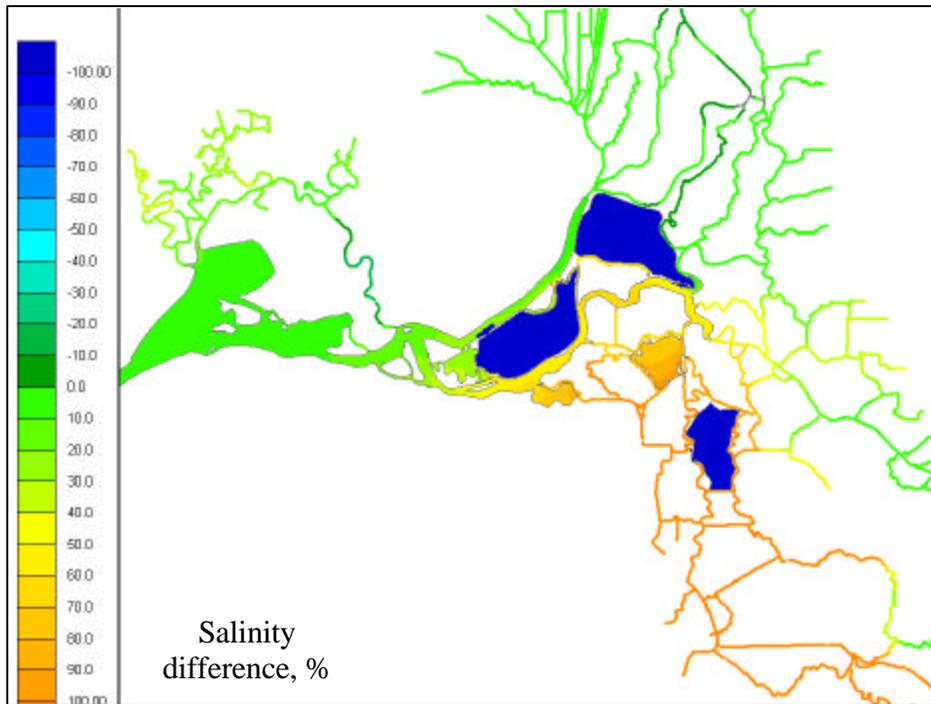


Figure 5-8 Salinity difference (%) for three breach case vs. base without exports, October 1.

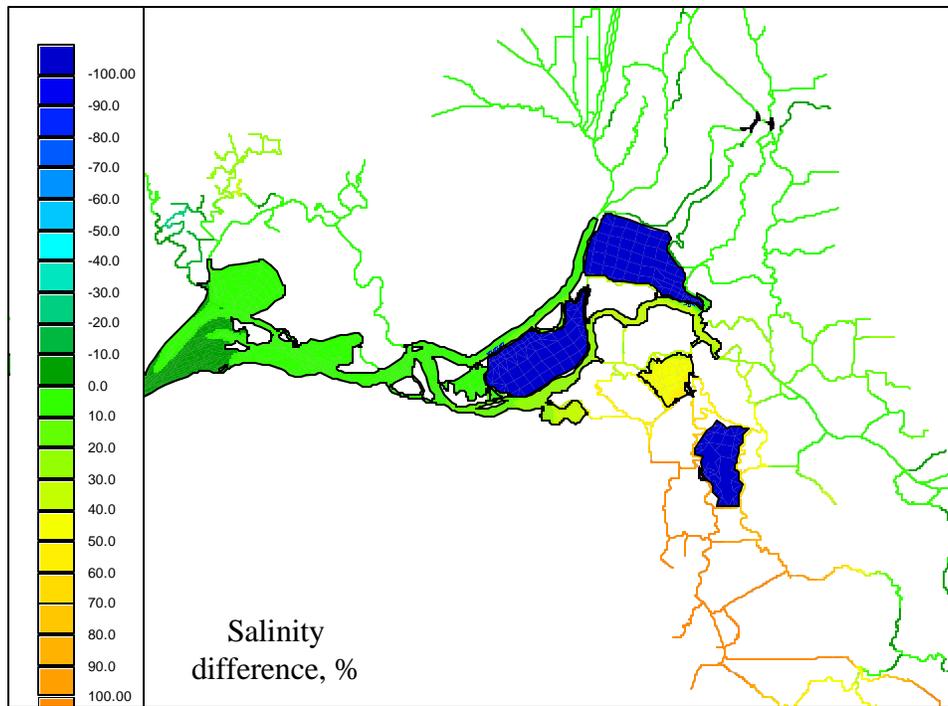


Figure 5-9 Salinity difference (%) for three breach case vs. base without exports, November 1.

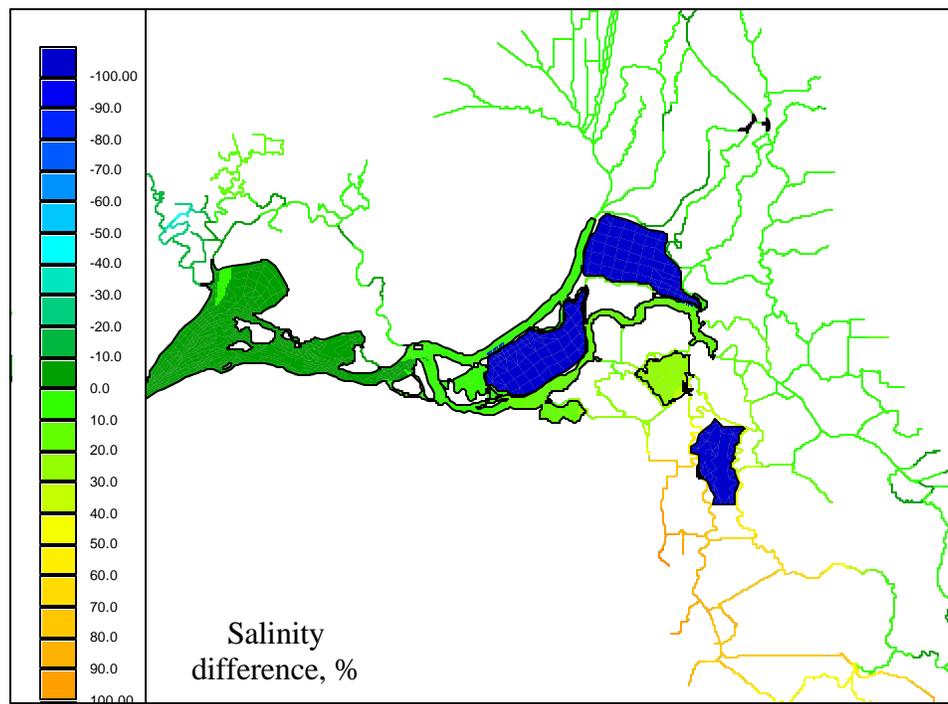


Figure 5-10 Salinity difference (%) for three breach case vs. base without exports, December 1.

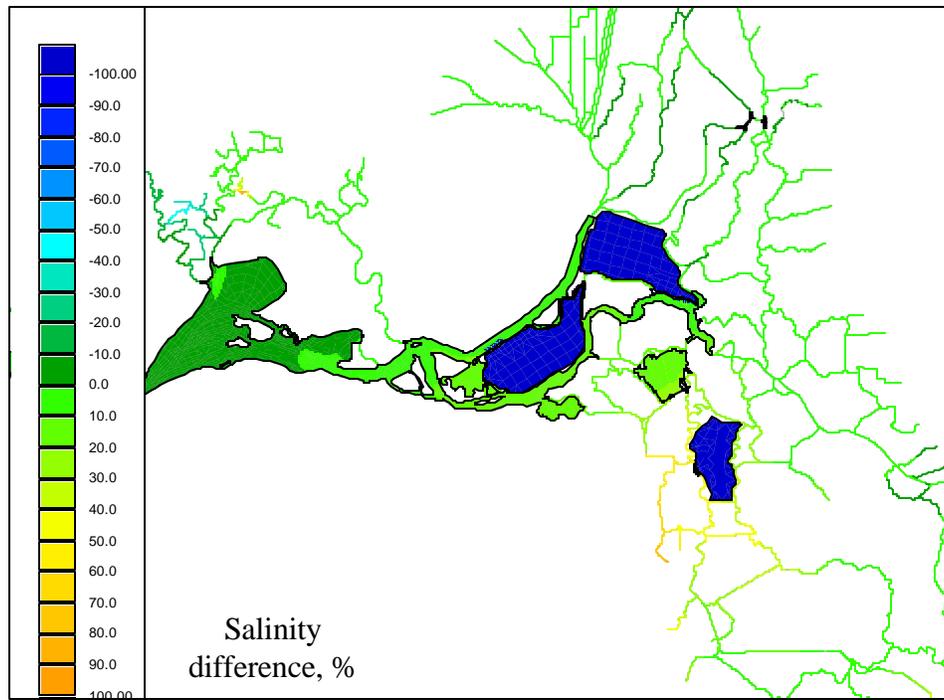


Figure 5-11 Salinity difference (%) for three breach case vs. base without exports, January 1.

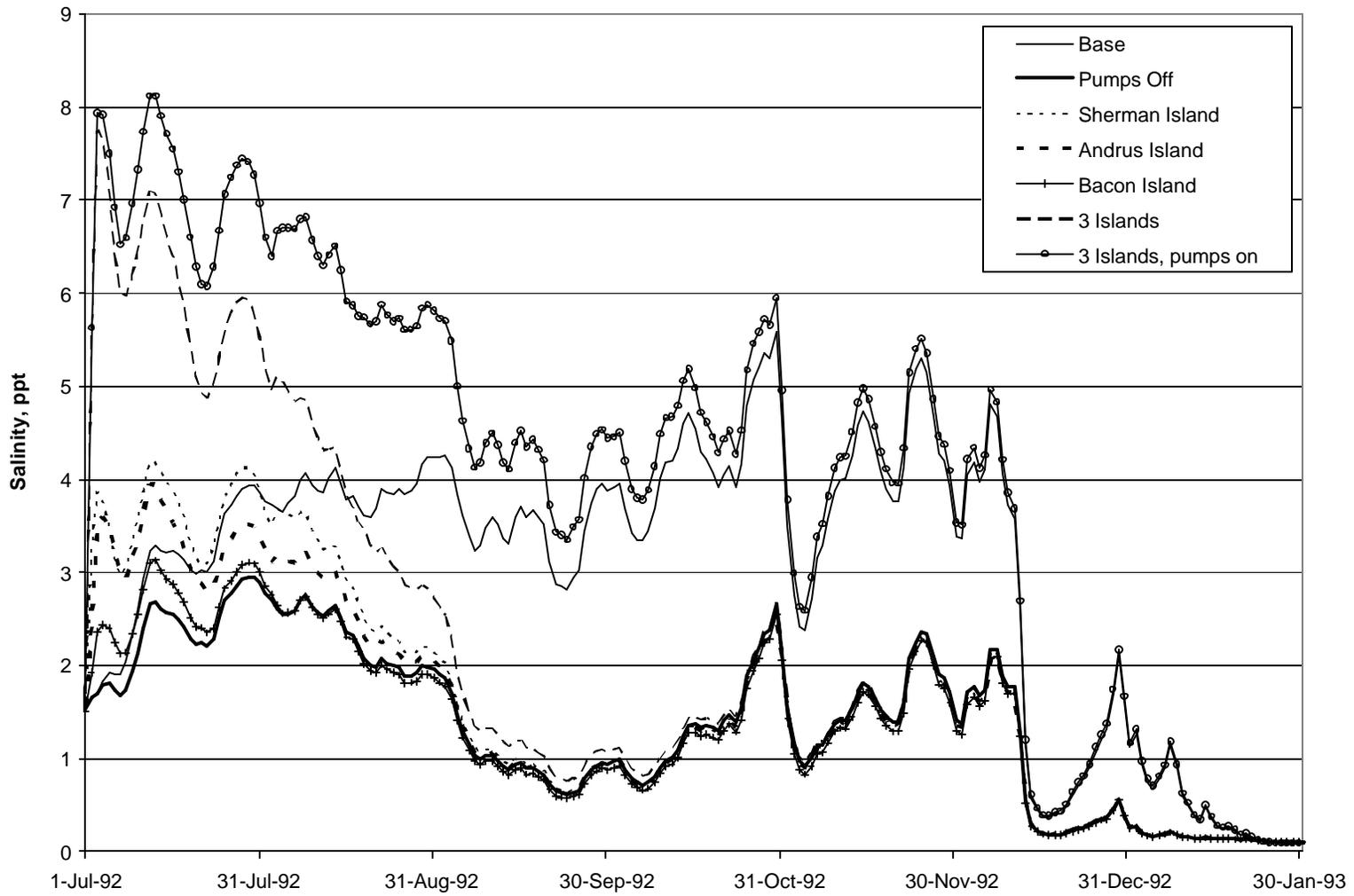


Figure 5-12 Time series of tidally averaged salinity at Collinsville.

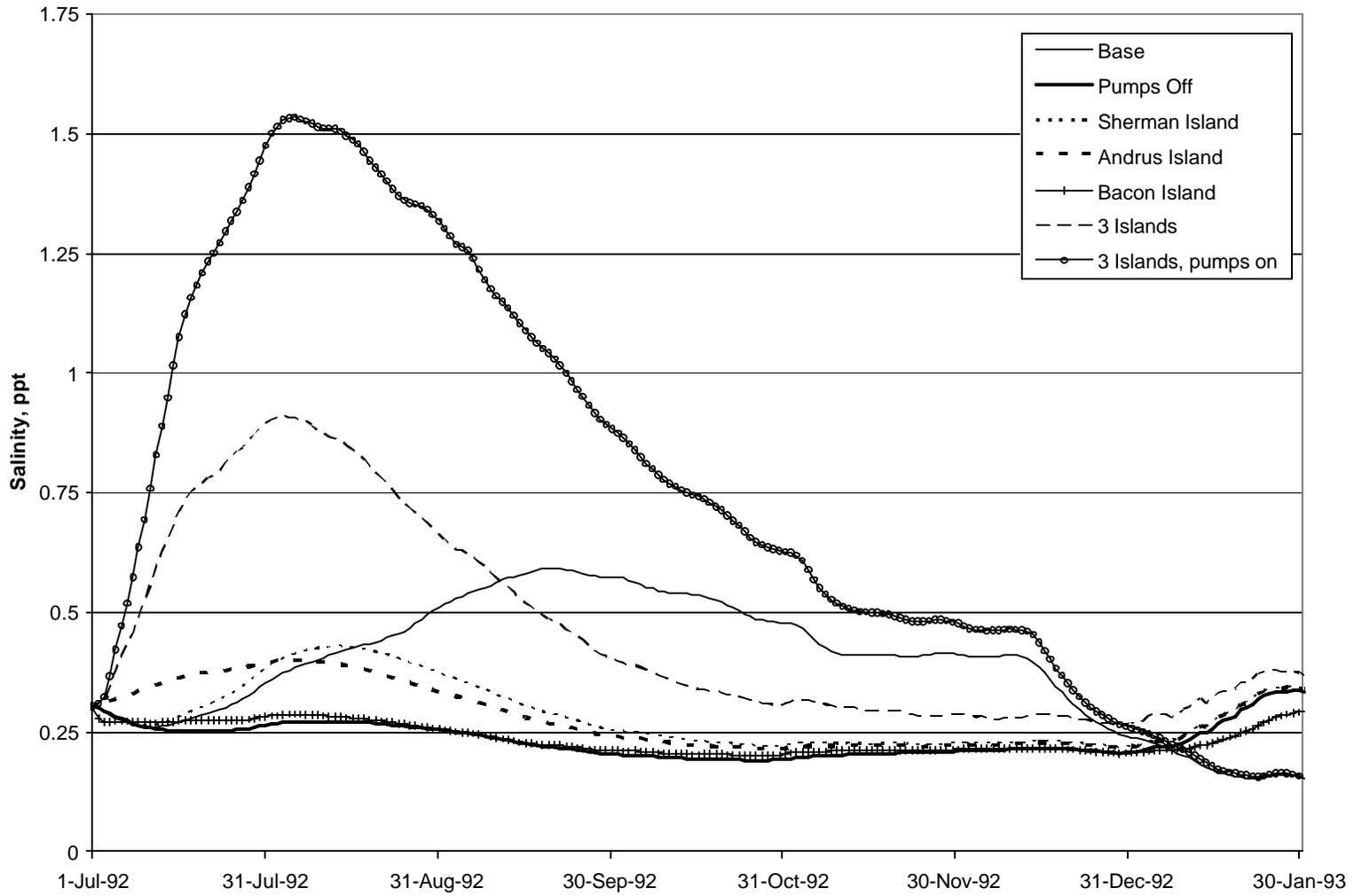


Figure 5-13 Time series of tidally averaged salinity at Old River just south of Franks Tract.

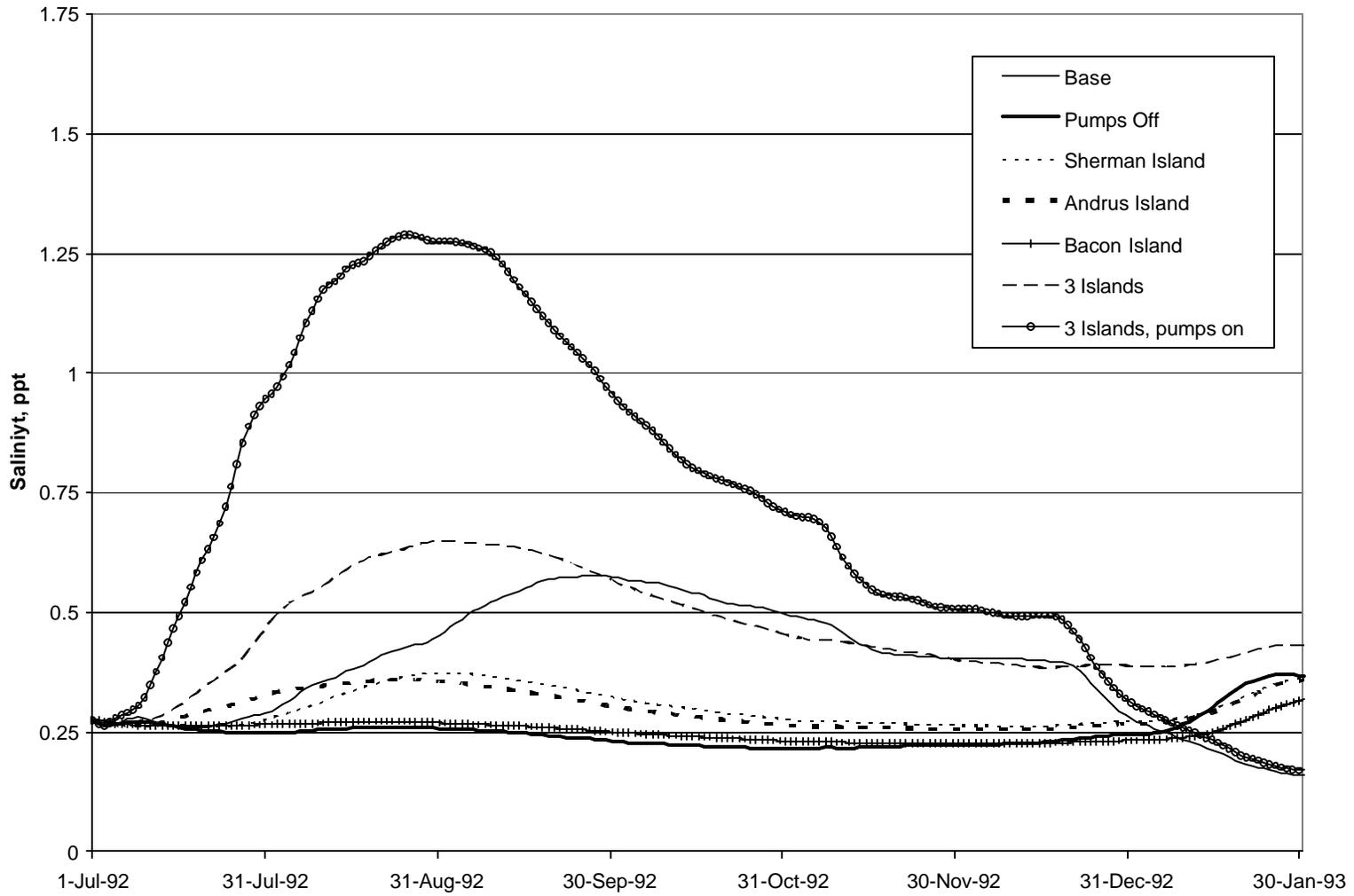


Figure 5-14 Time series of tidally averaged salinity at Contra Costa intake.

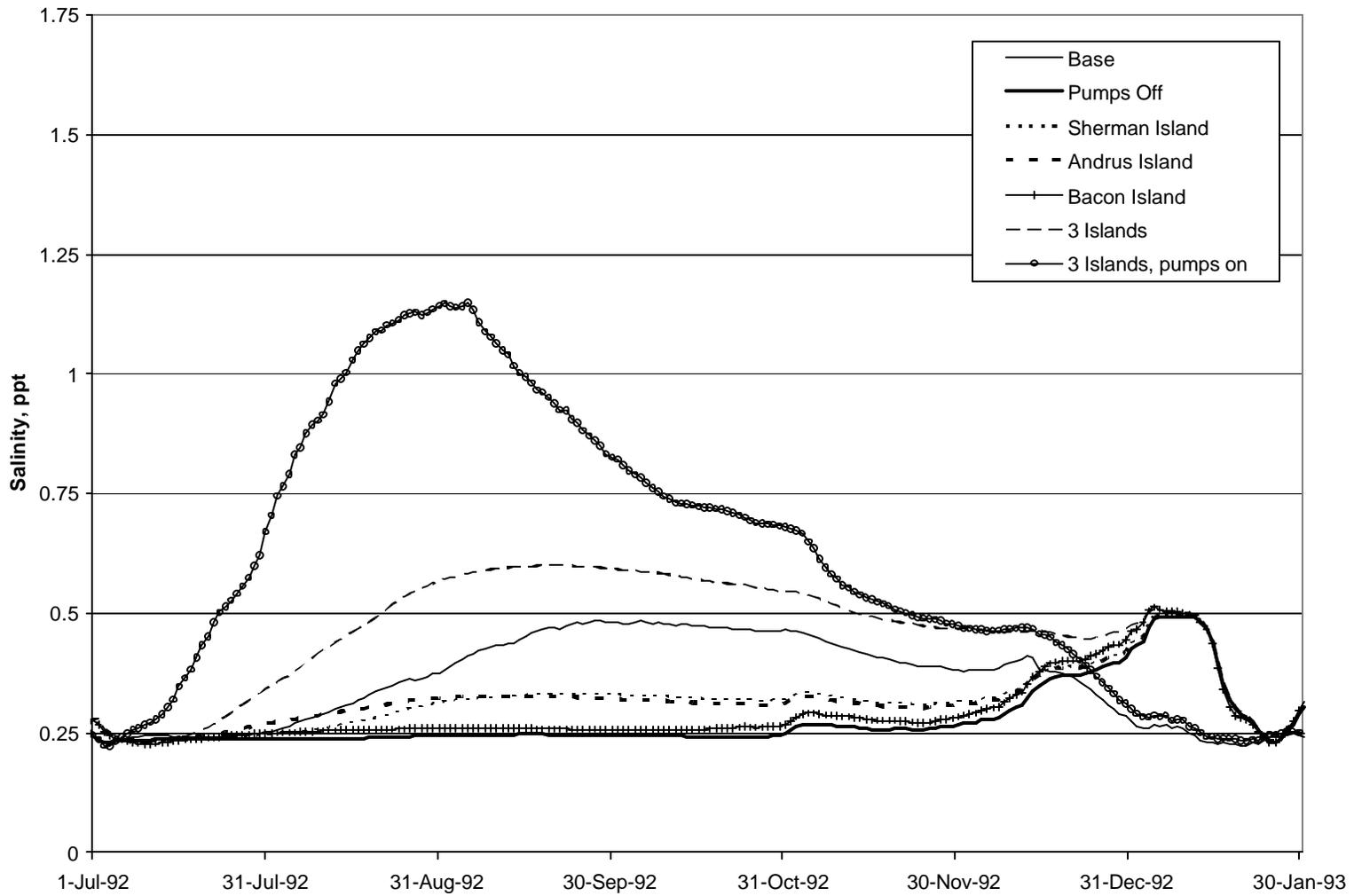


Figure 5-15 Time series of tidally averaged salinity at State Water Project intake.

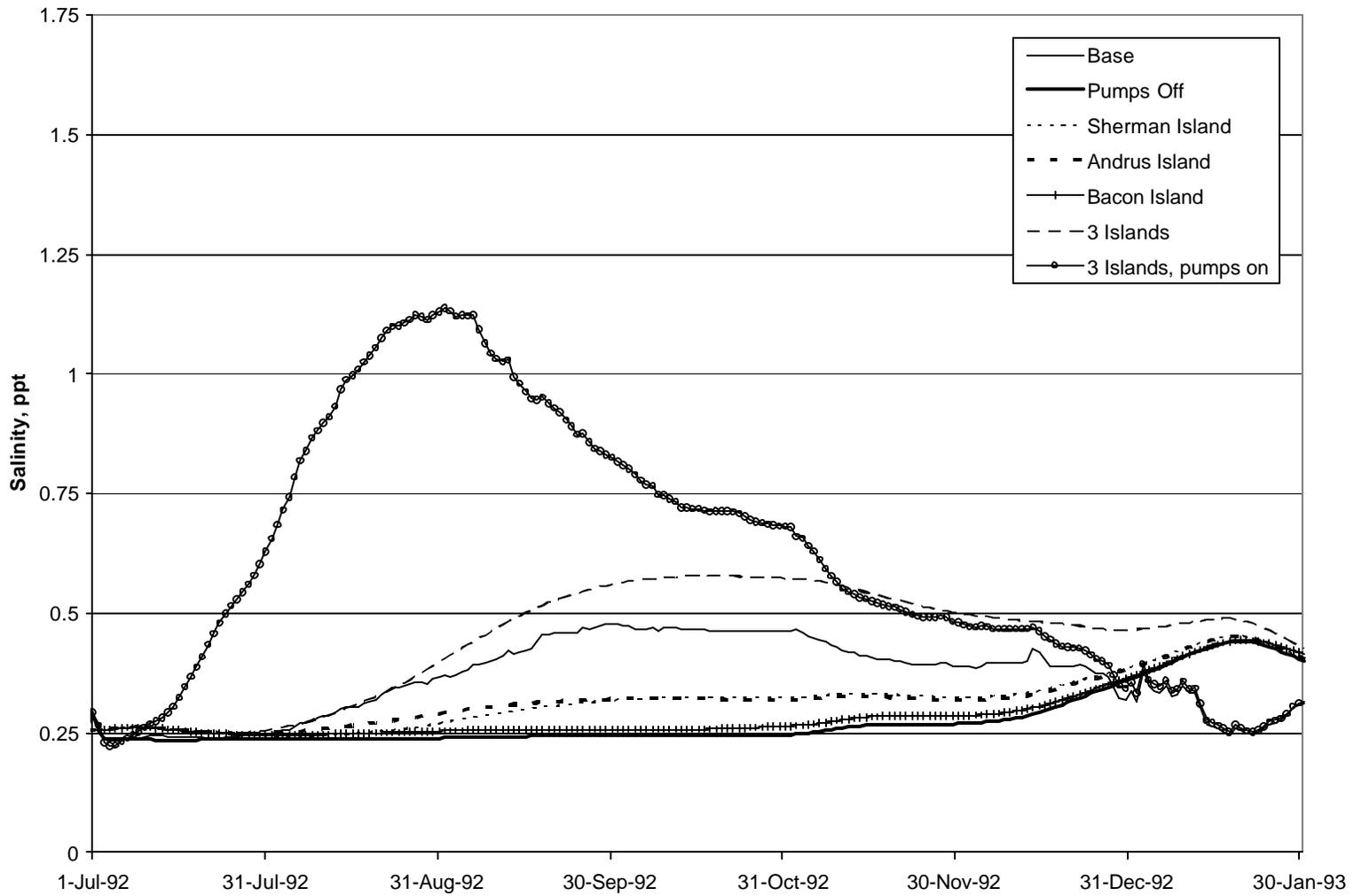


Figure 5-16 Time series of tidally averaged salinity at Central Valley Project intake.

## **6 APPENDIX: REPRESENTATIVE CALIBRATION PLOTS**

The following figures are excerpts from the most recent calibration exercise which is part of the ongoing investigation of the impacts of flooded islands by DWR and other agencies. These plots are intended to illustrate the capabilities and limitations of the model. A full calibration report will be developed as part of the on-going Franks Tract work and is expected to be available before June of 2004.

These results were produced with the tidal boundary applied at Martinez rather than the Golden Gate.

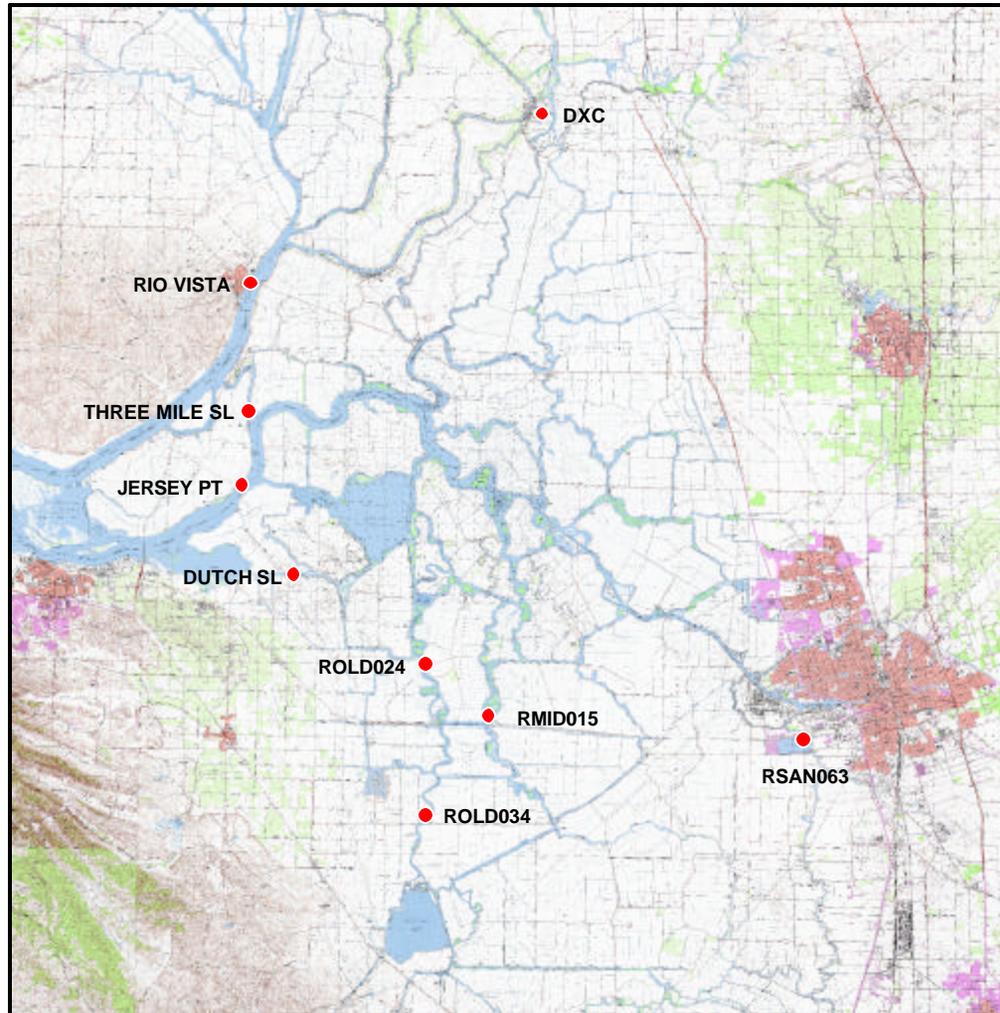
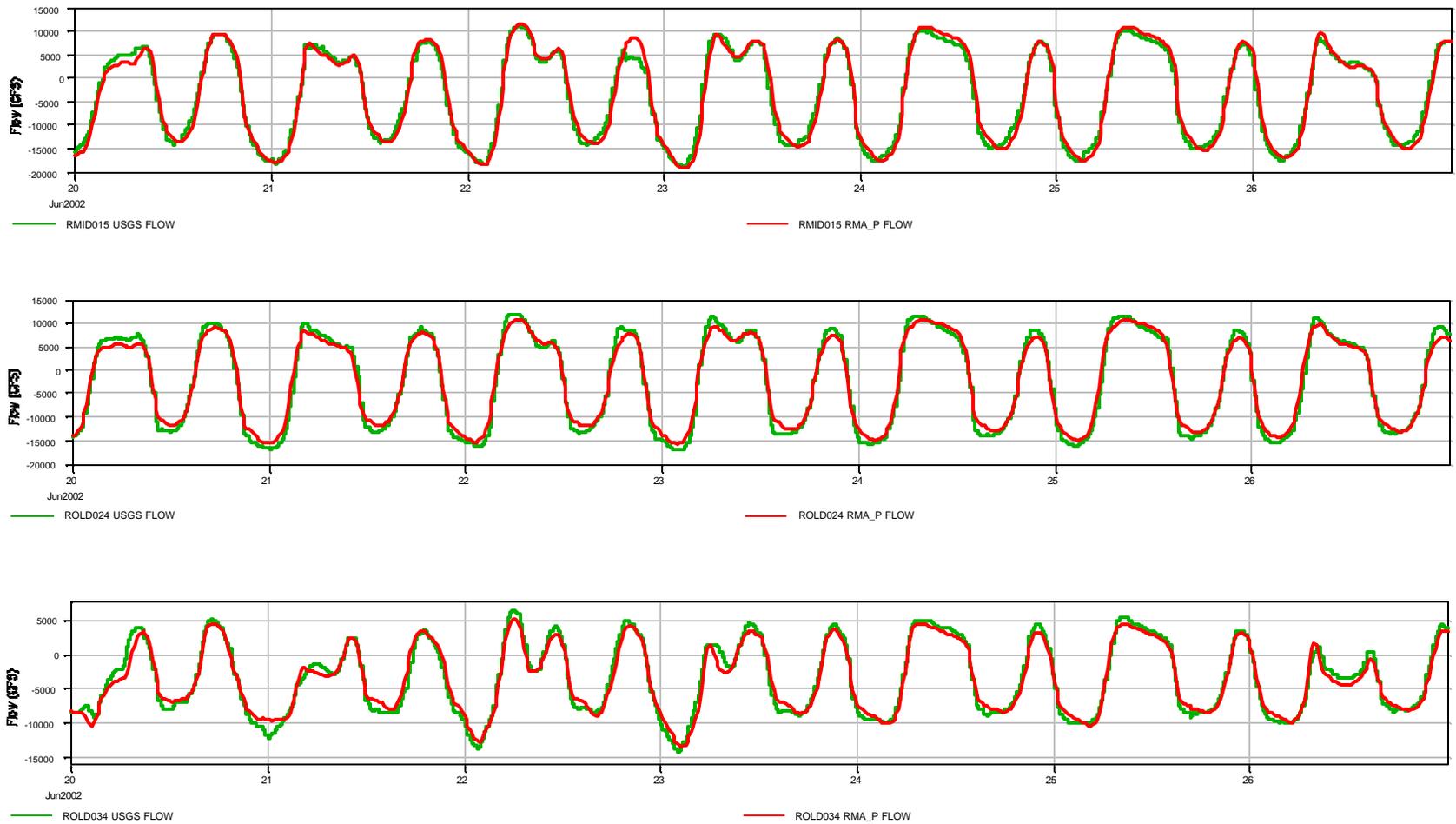
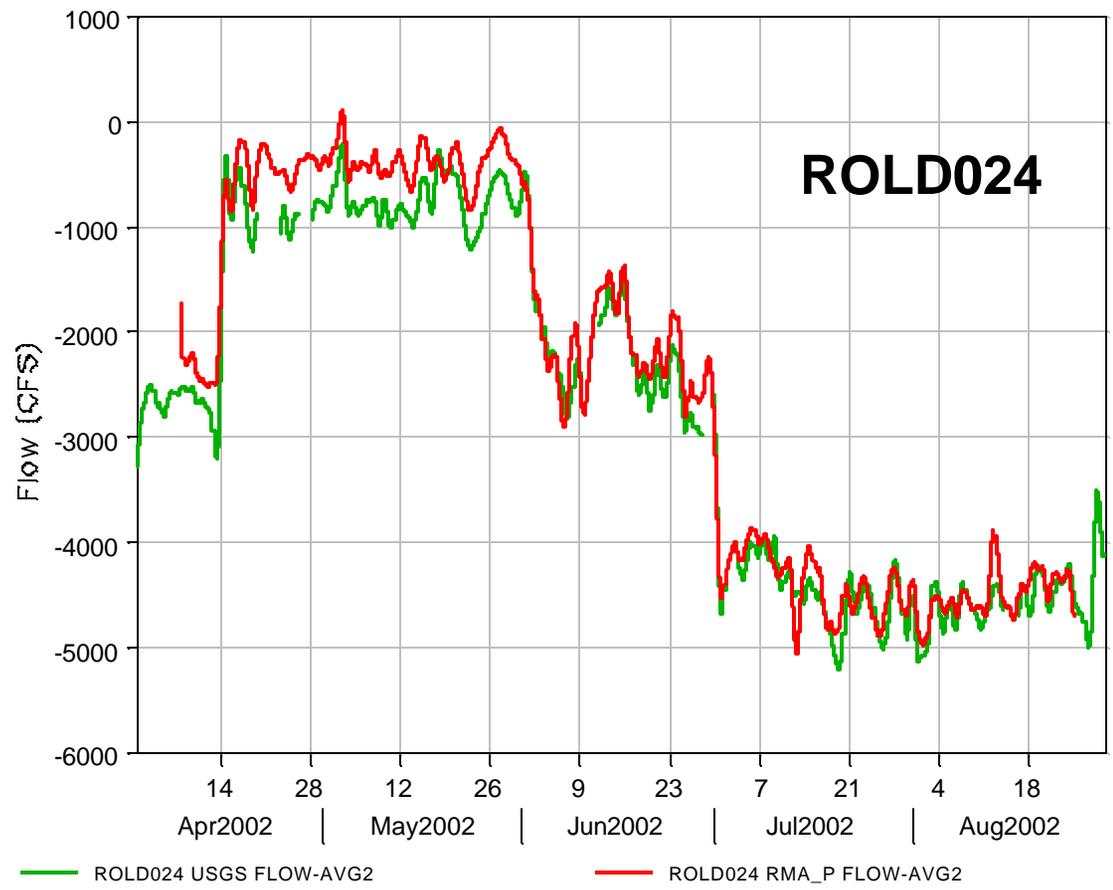


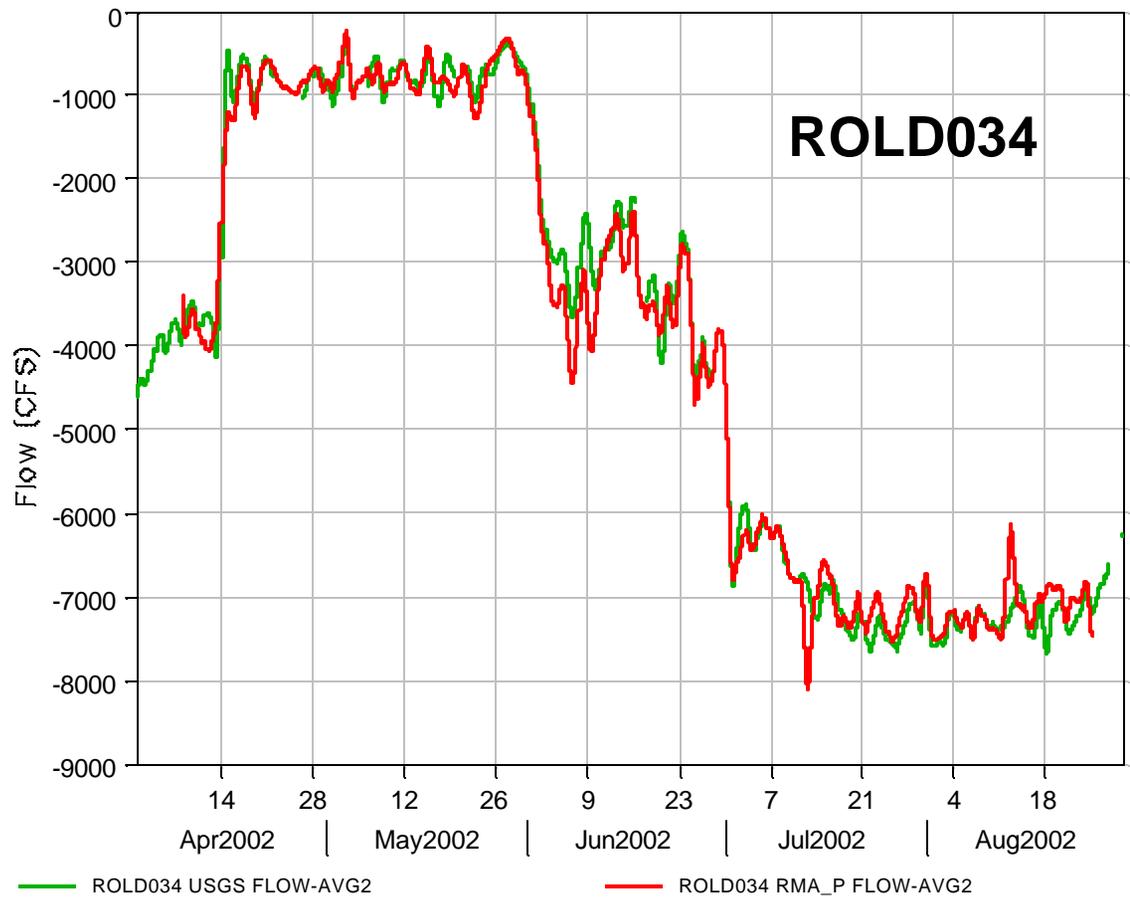
Figure 6-1 Delta flow Meter Locations.



**Figure 6-2 Delta flow comparisons for RMID015, ROLD024 and ROLD034, June 20 – 26, 2002.**



**Figure 6-3 Tidally averaged flow comparison at ROLD024.**



**Figure 6-4 Tidally averaged flow comparison at ROLD034.**

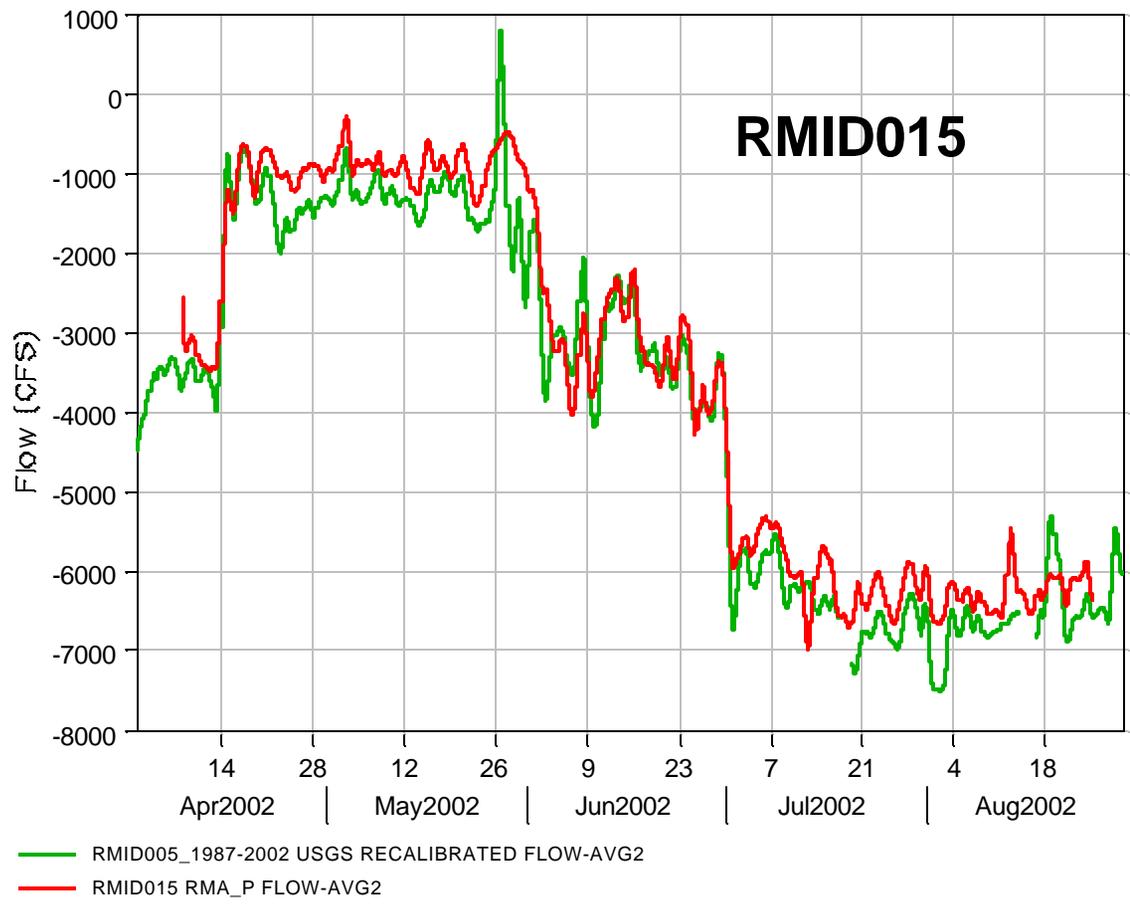
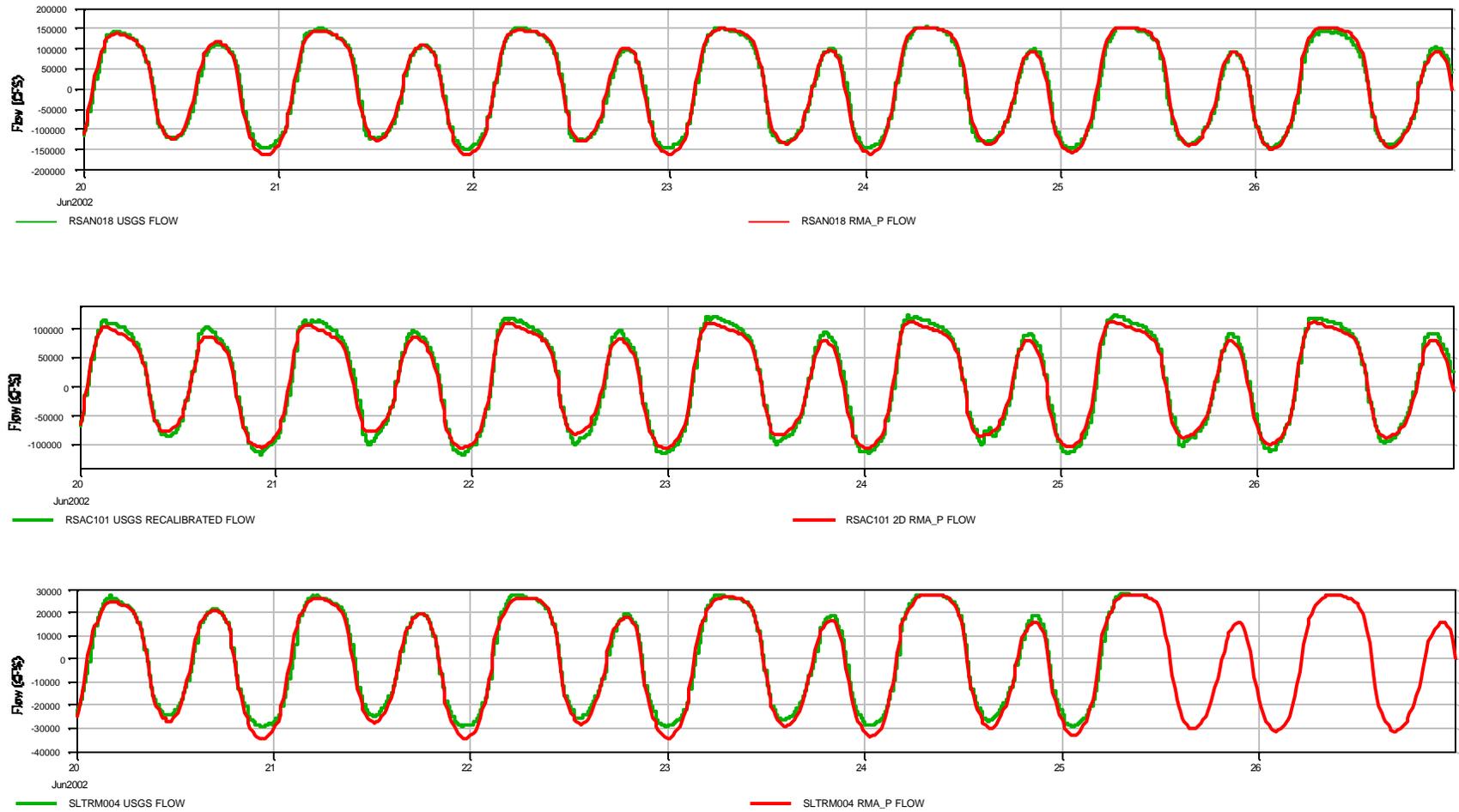
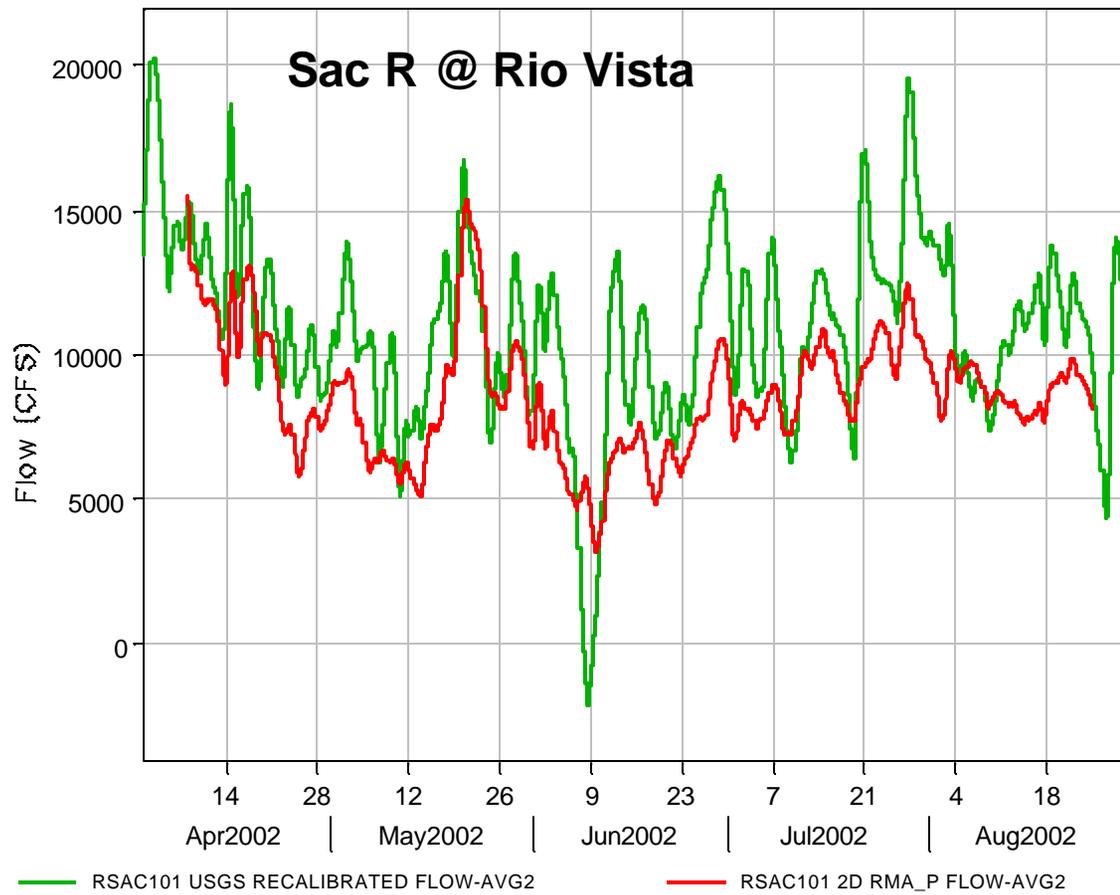


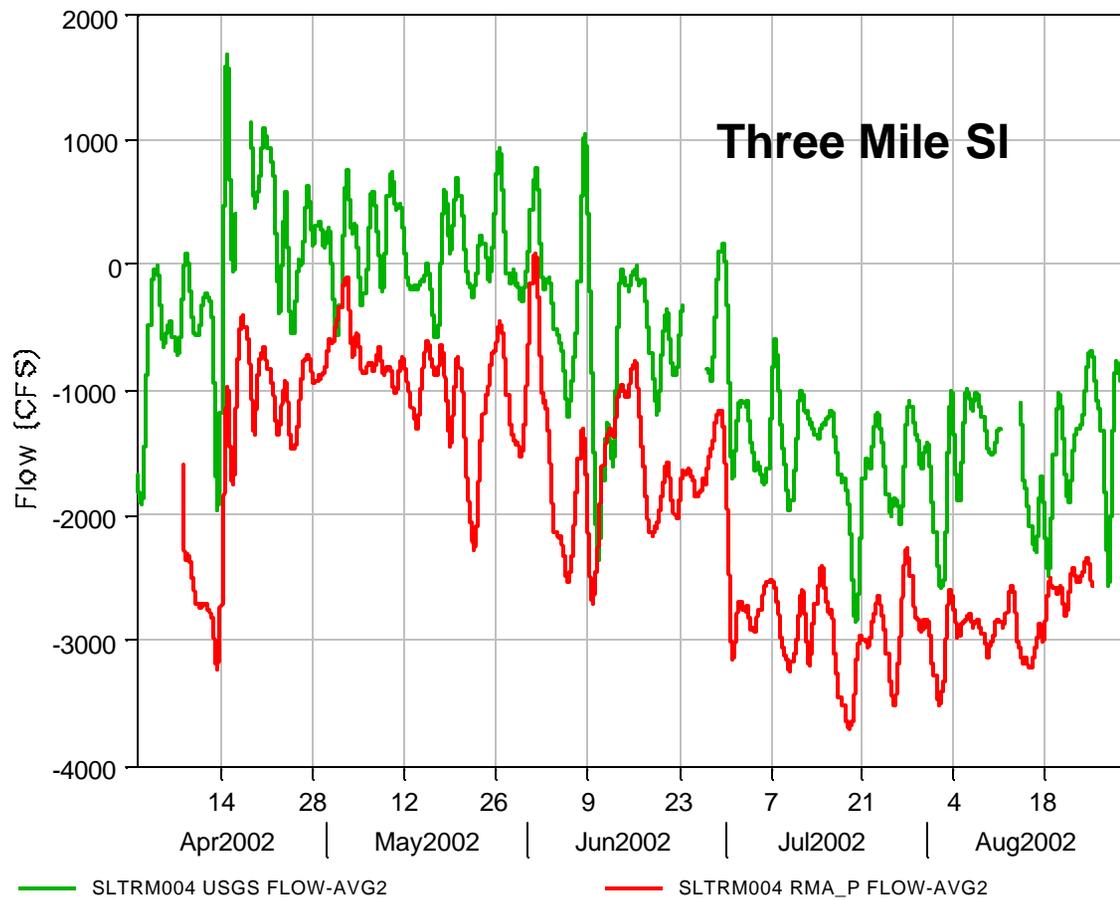
Figure 6-5 Tidally averaged flow comparison at RMID015.



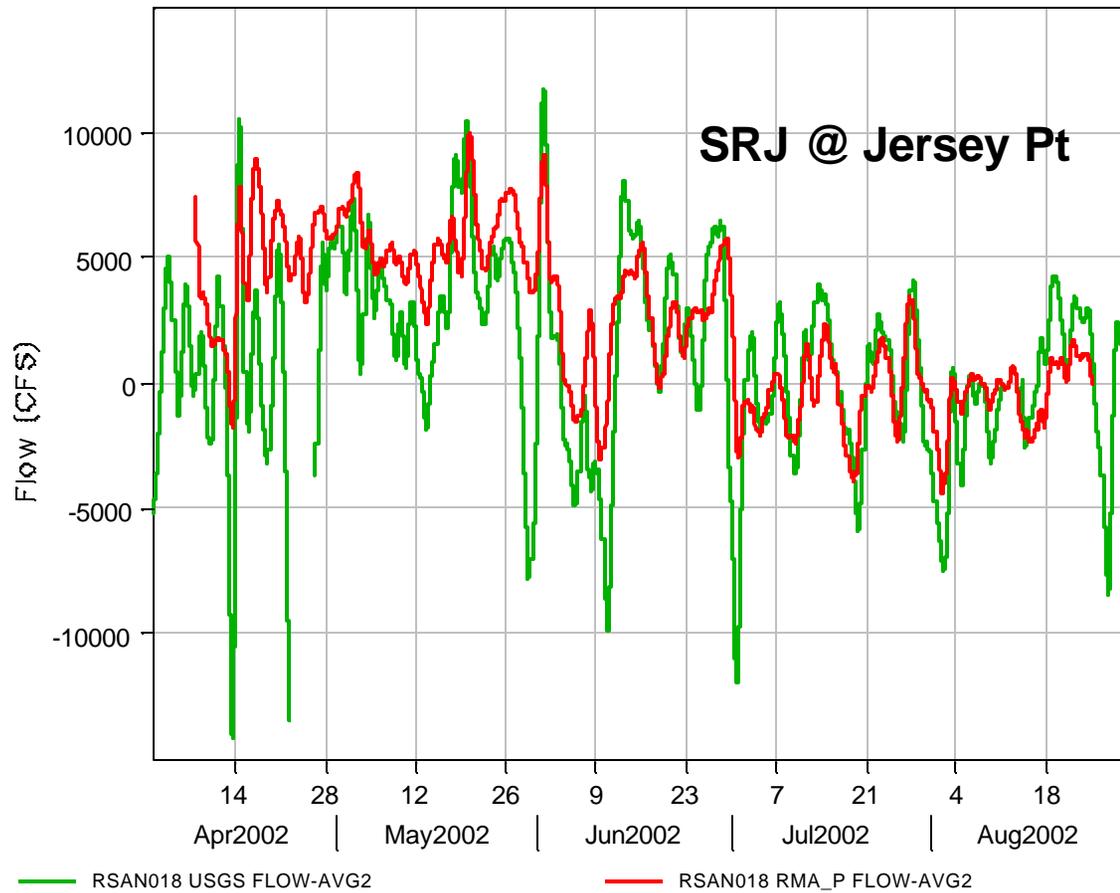
**Figure 6-6 Delta flow comparisons for Rio Vista, Three Mile Slough and Jersey Point, June 20 – 26, 2002.**



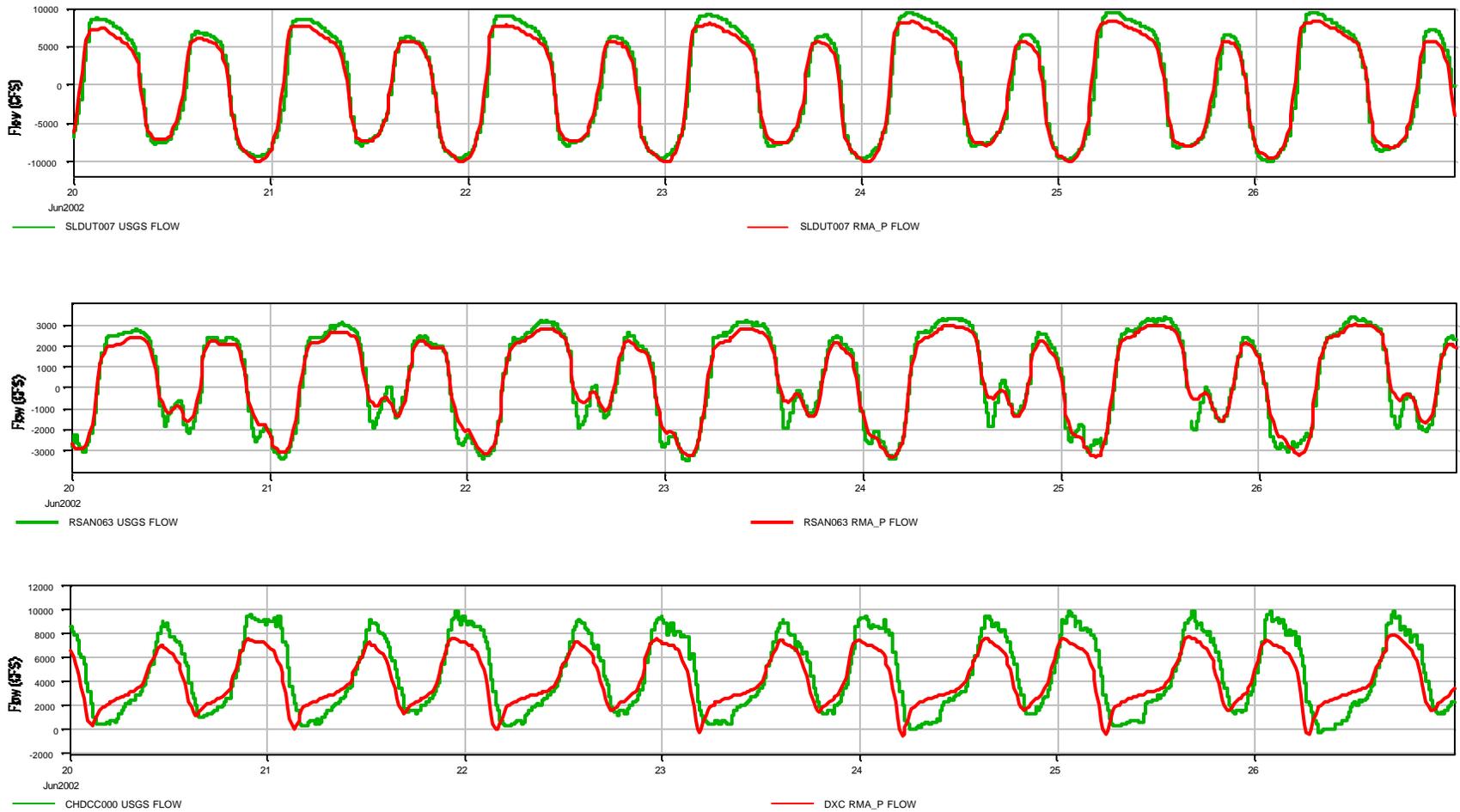
**Figure 6-7 Tidally averaged flow comparison at Rio Vista.**



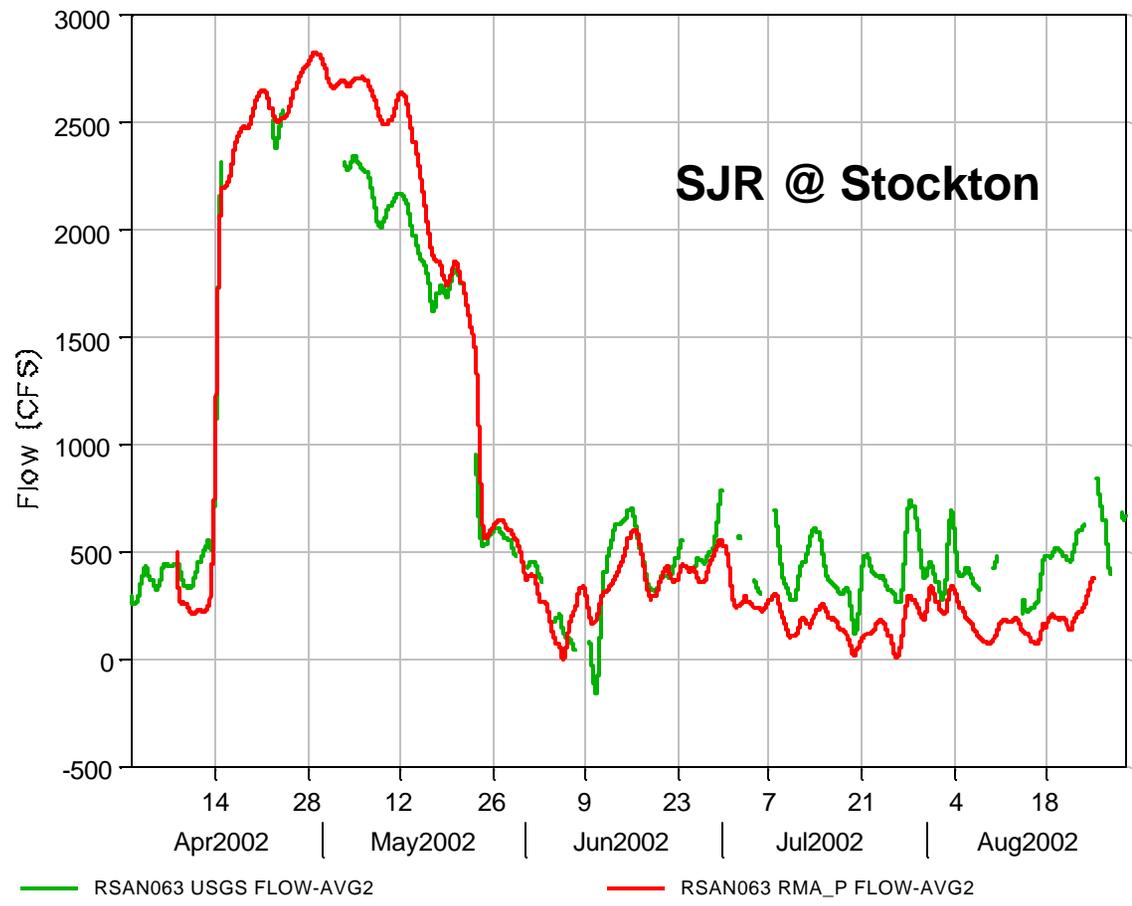
**Figure 6-8 Tidally averaged flow comparison at Three Mile Slough.**



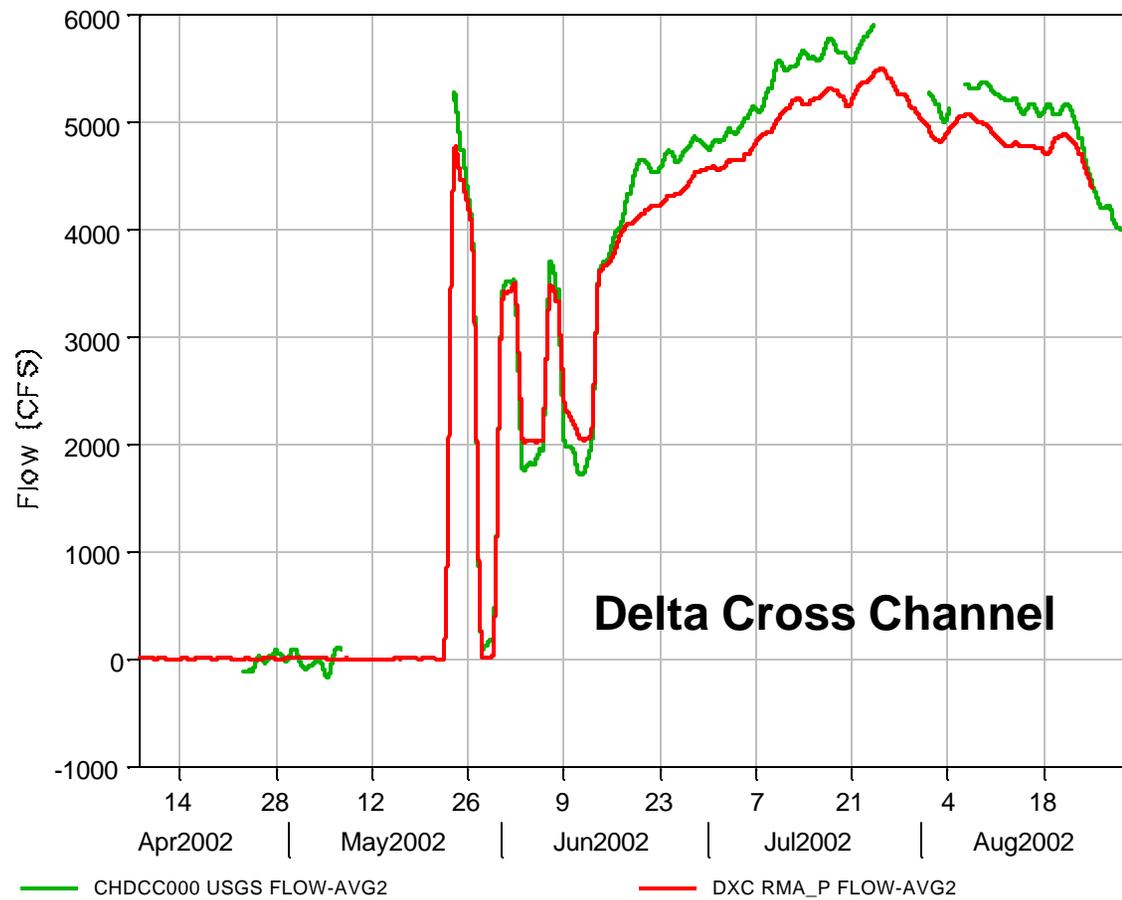
**Figure 6-9 Tidally averaged flow comparison in the San Joaquin River at Jersey Point.**



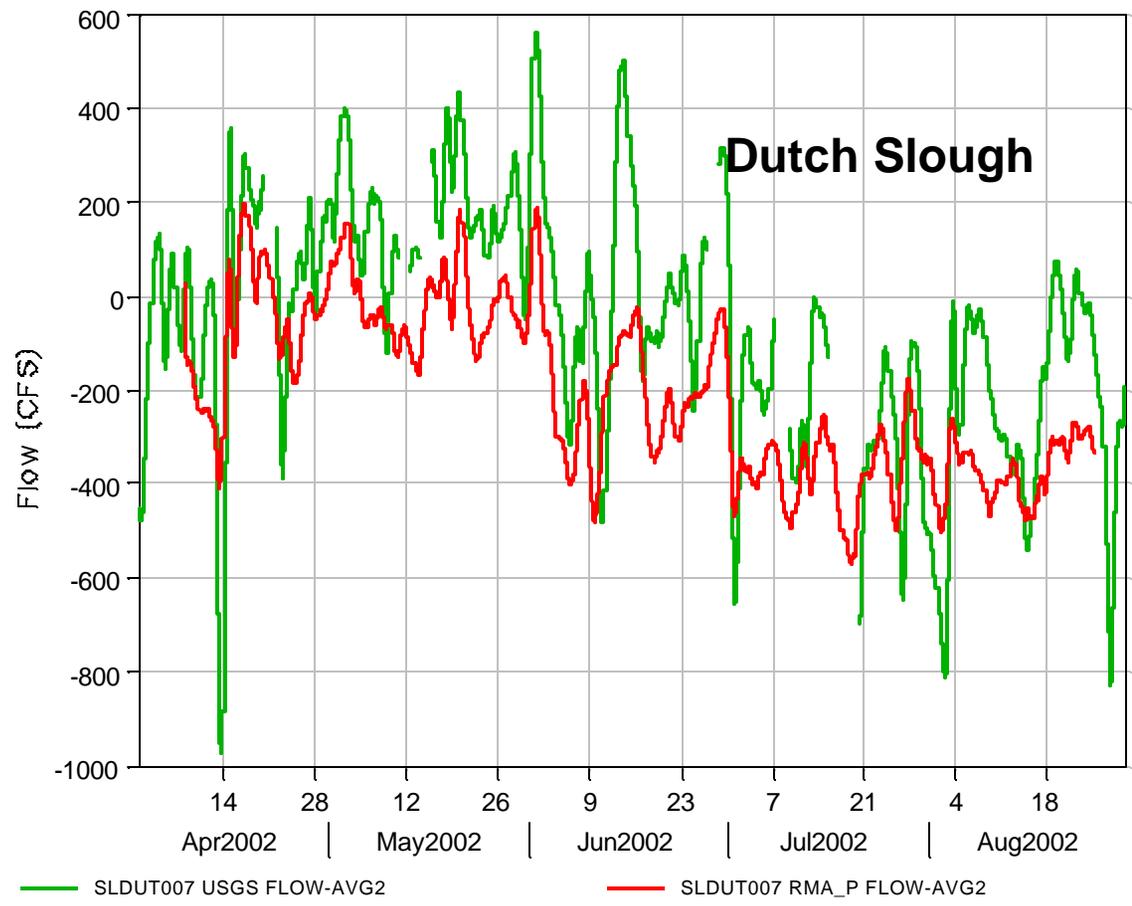
**Figure 6-10 Delta flow comparisons for Dutch Slough, San Joaquin at Stockton, and Delta Cross Channel, June 20 – 26, 2002.**



**Figure 6-11 Tidally averaged flow comparison in the San Joaquin River at Stockton.**



**Figure 6-12 Tidally averaged flow comparison at the Delta Cross Channel.**



**Figure 6-13 Tidally averaged flow comparison at Dutch Slough.**

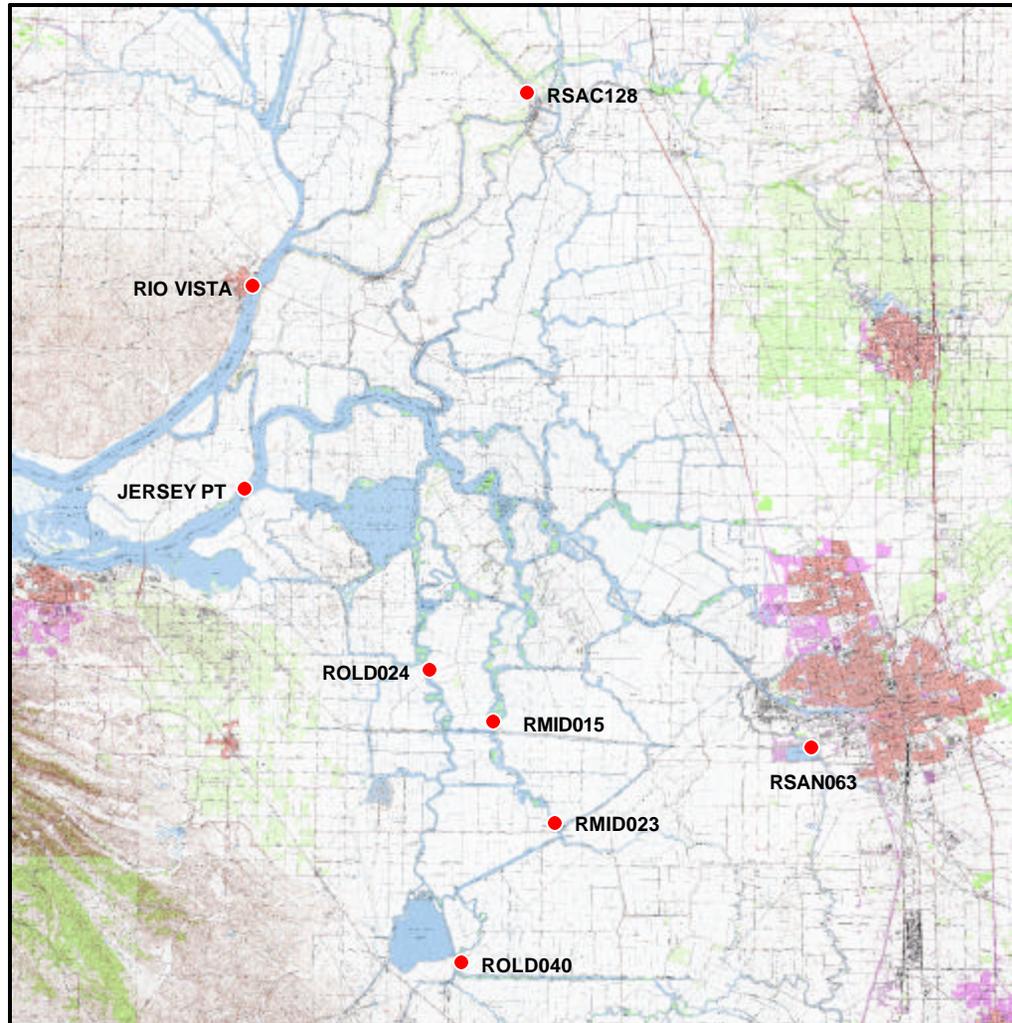
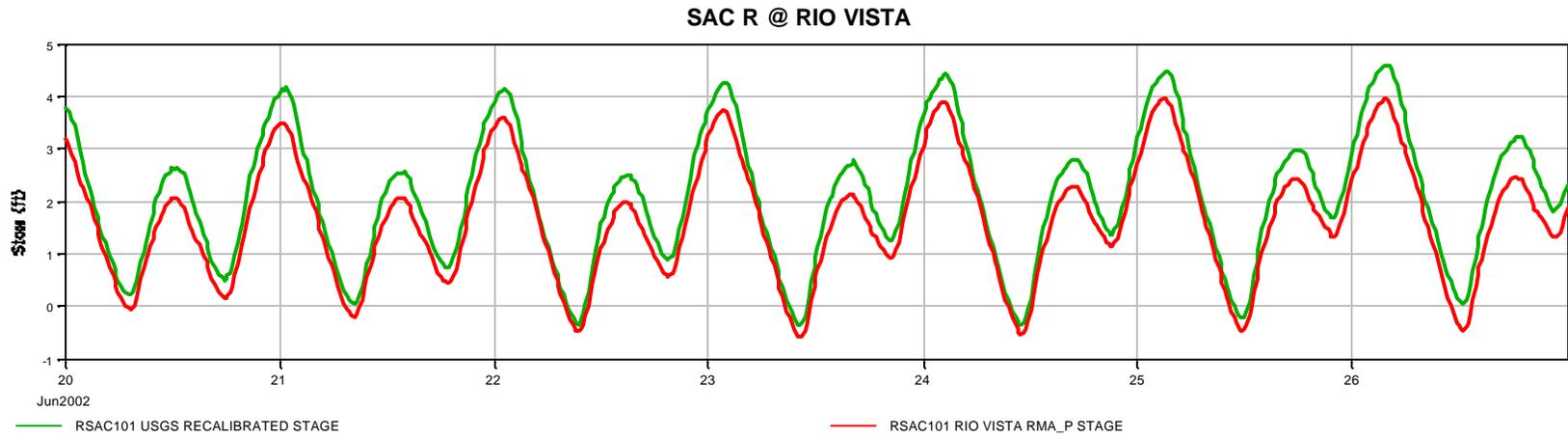
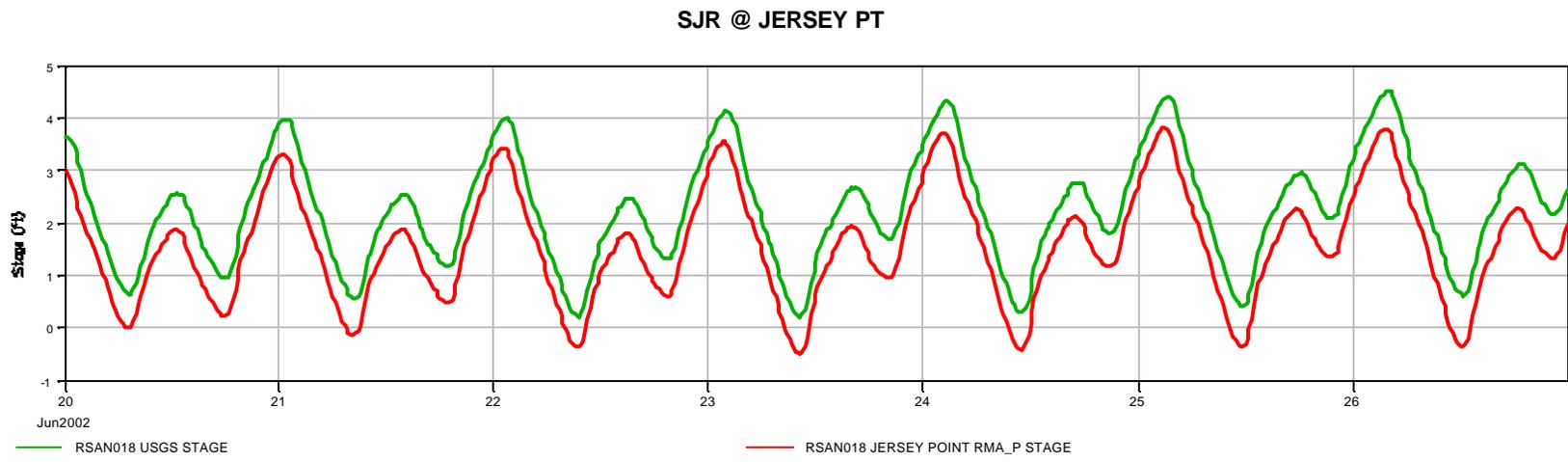
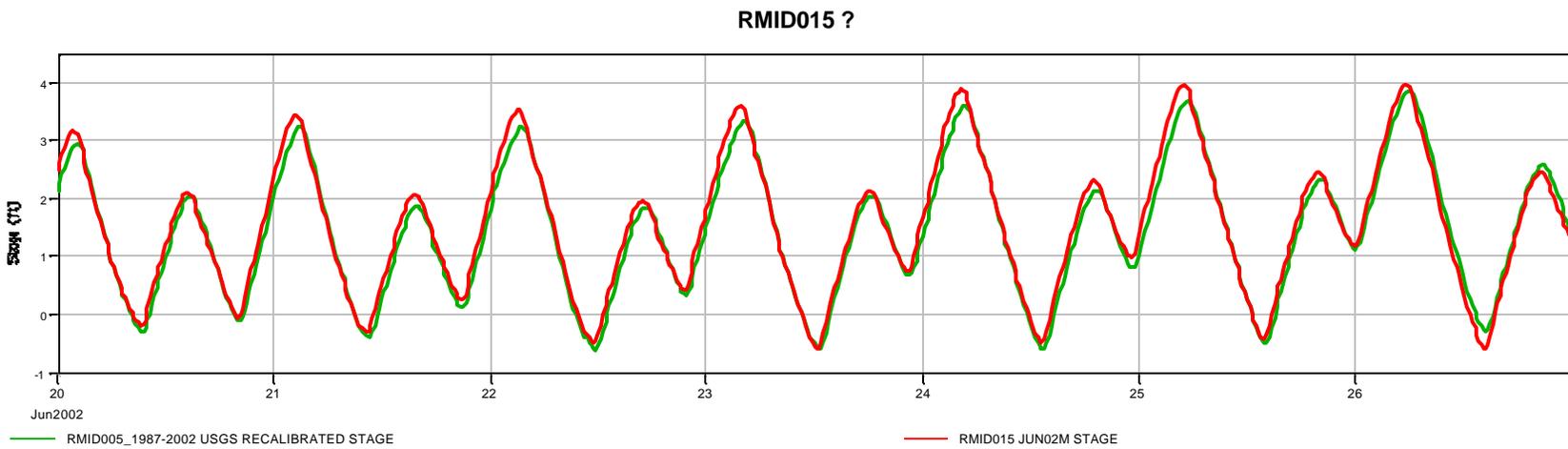
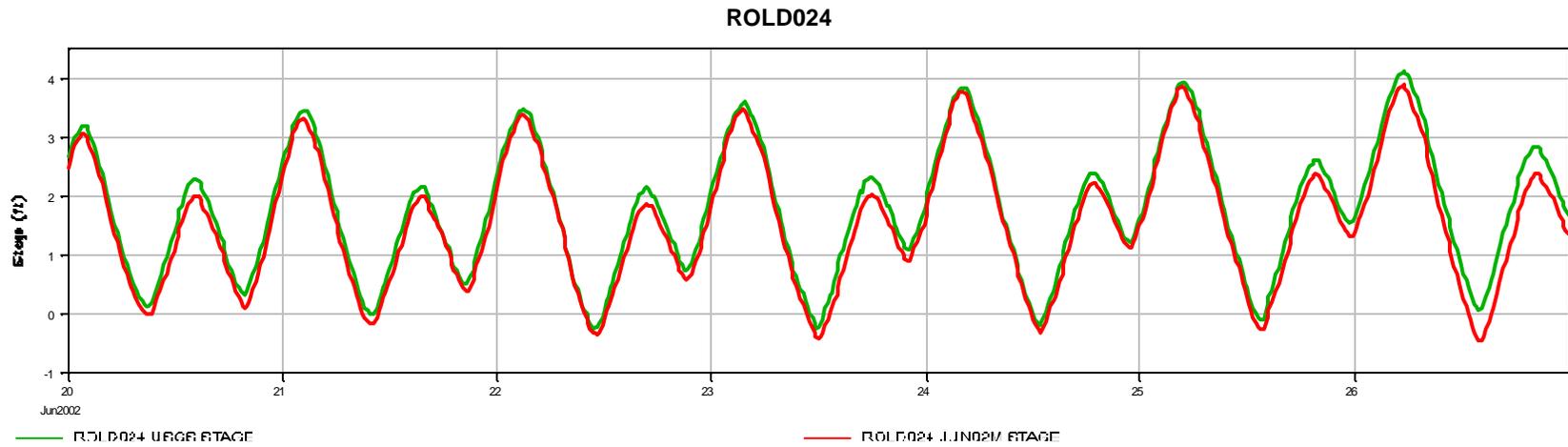


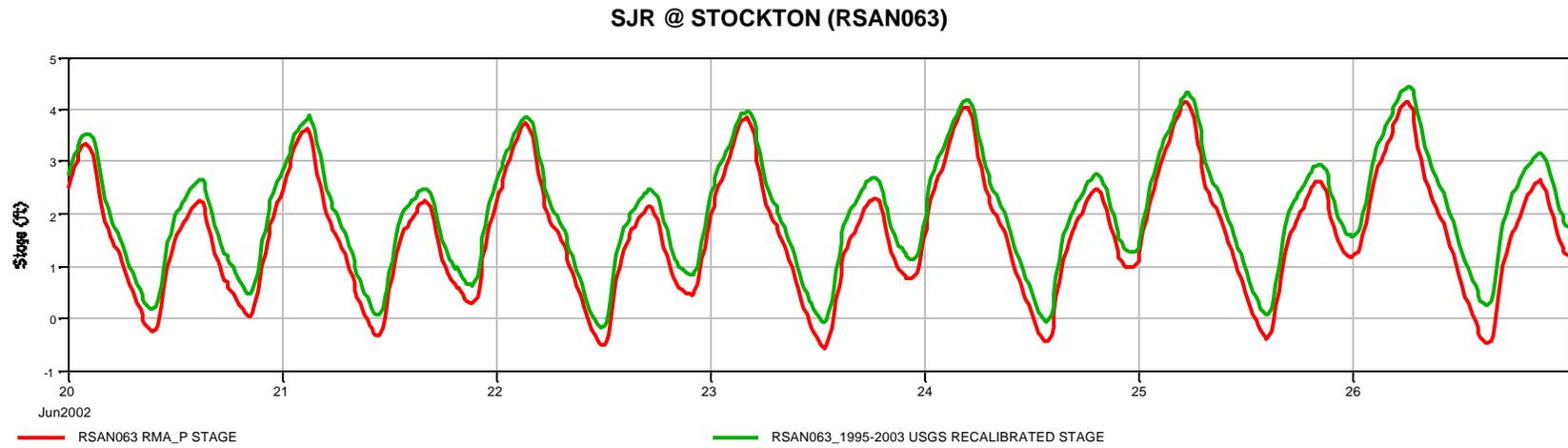
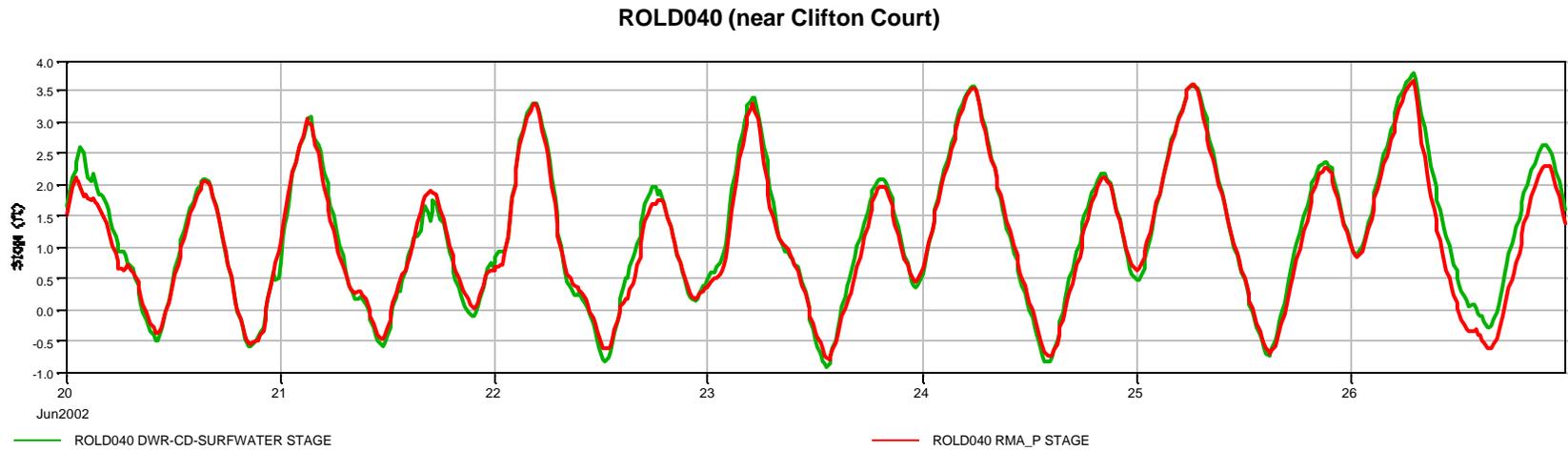
Figure 6-14 Delta Stage Locations.



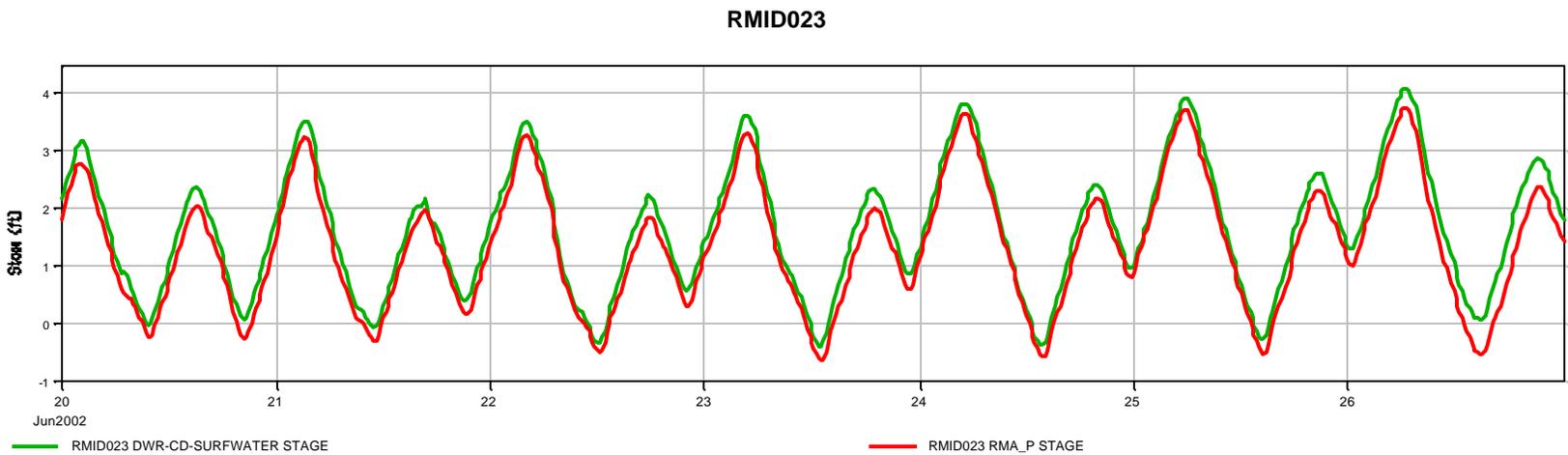
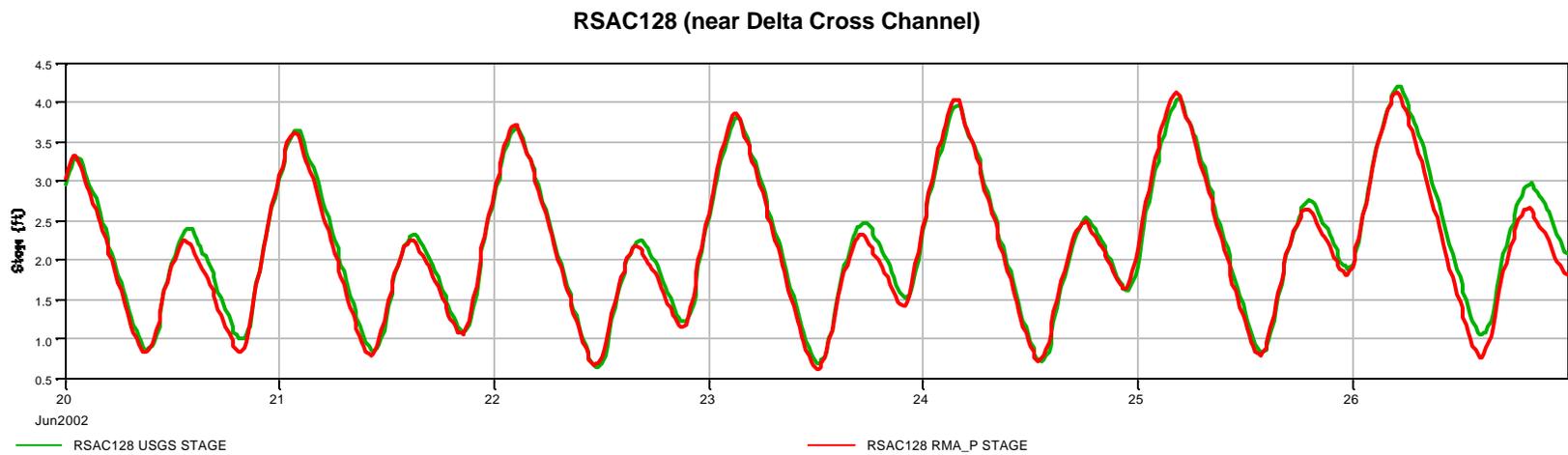
**Figure 6-15 Delta stage comparisons for June 20 – 26, 2002.**



**Figure 6-16 Delta stage comparisons for June 20 – 26, 2002.**



**Figure 6-17 Delta stage comparisons for June 20 – 26, 2002.**



**Figure 6-18 Delta stage comparisons for June 20 – 26, 2002.**

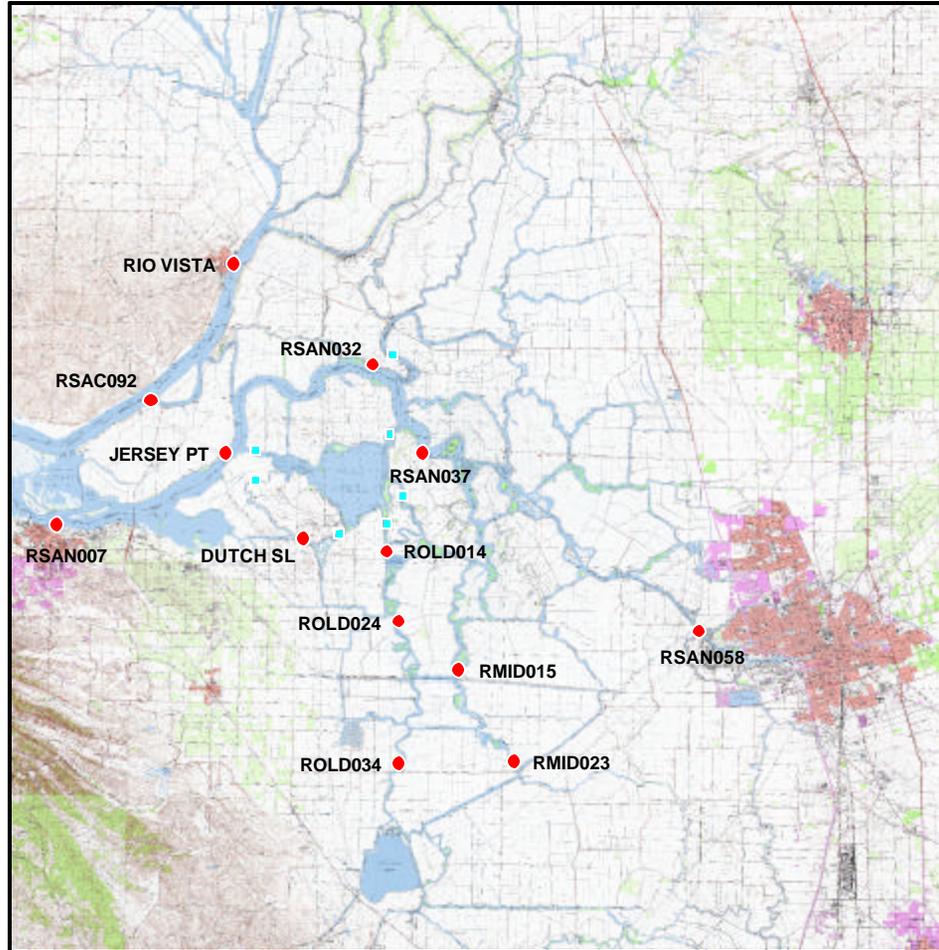
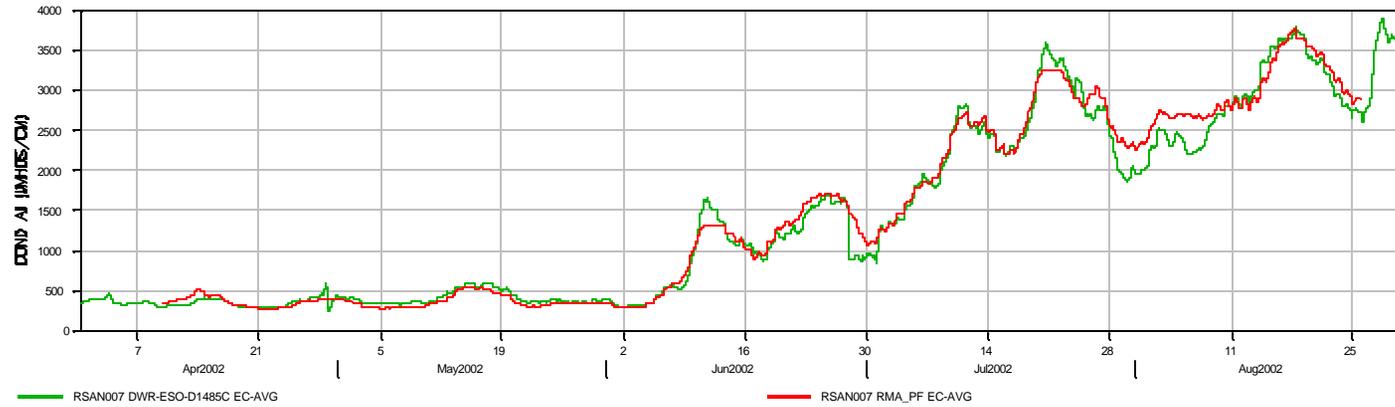


Figure 6-19 Delta EC Instrument Locations.

### RSAN007



### Jersey Point

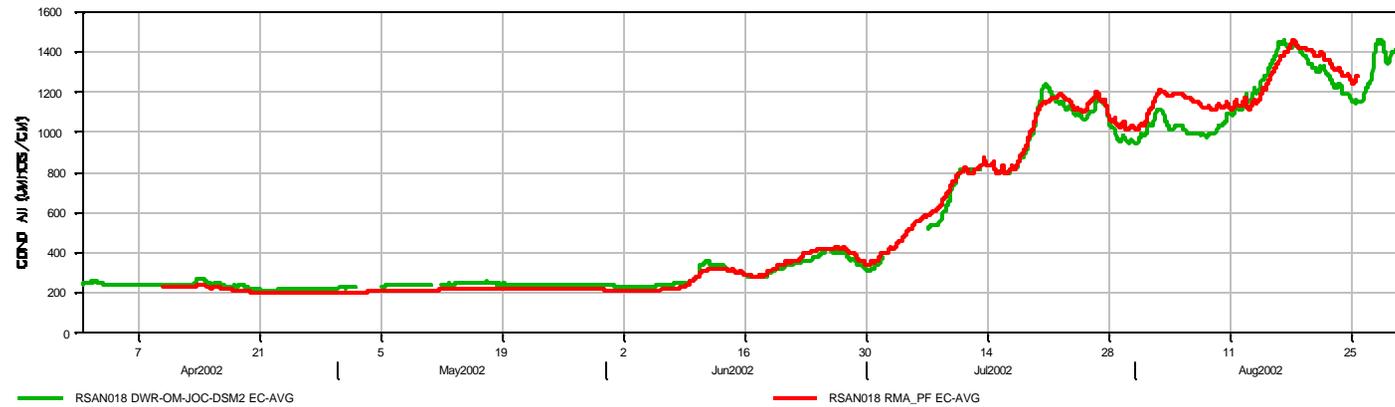
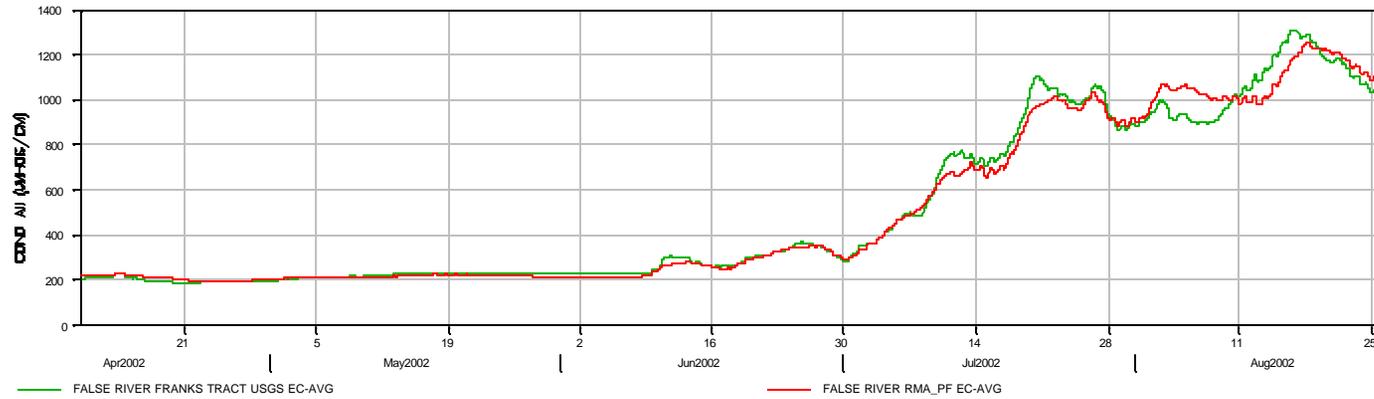


Figure 6-20 Tidally averaged Delta EC comparisons for April – August, 2002.

### False River



### RSAN032

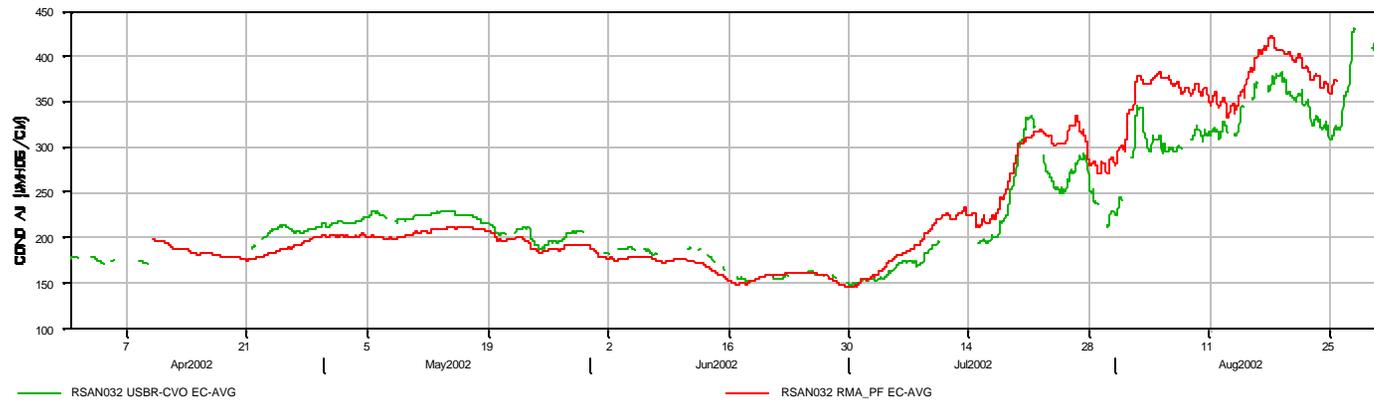
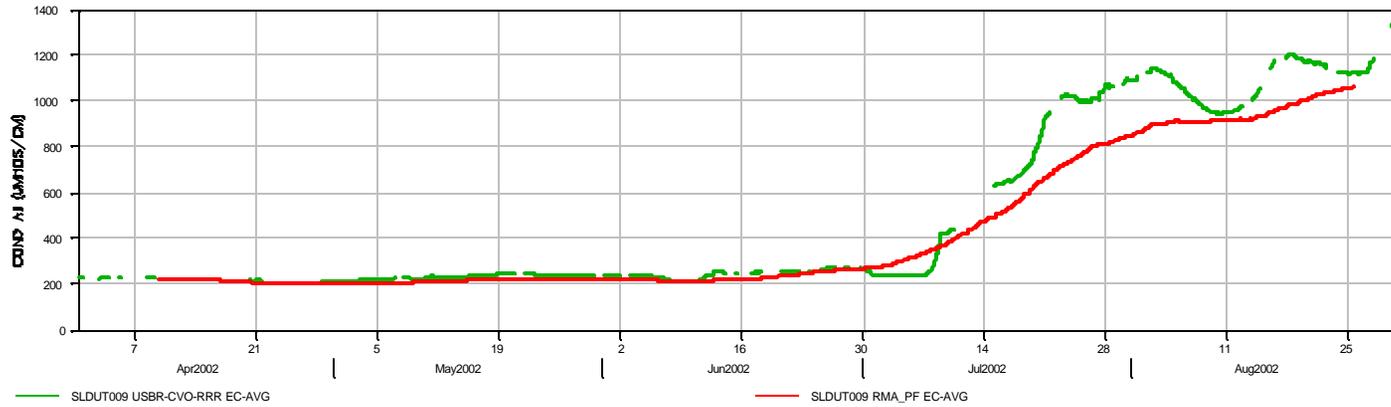


Figure 6-21 Tidally averaged Delta EC comparisons for April – August, 2002.

### Dutch Slough



### Sand Mound Slough

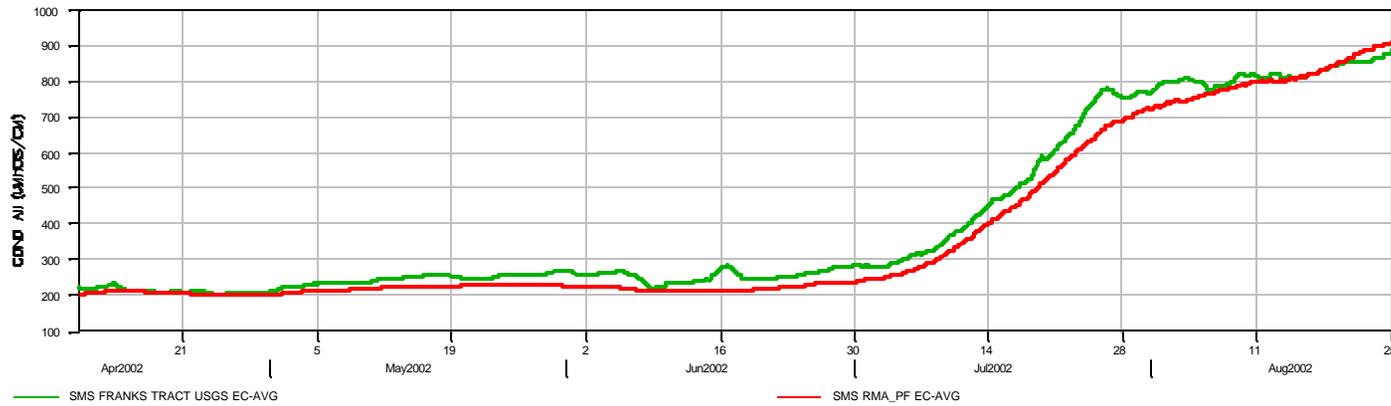
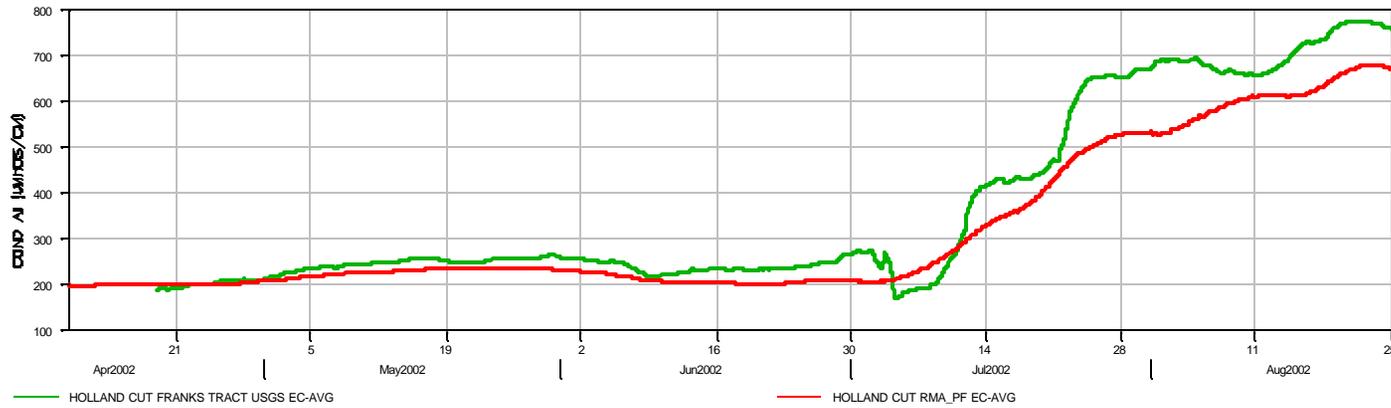


Figure 6-22 Tidally averaged Delta EC comparisons for April – August, 2002.

### Holland Cut



### Old River, Mandeville

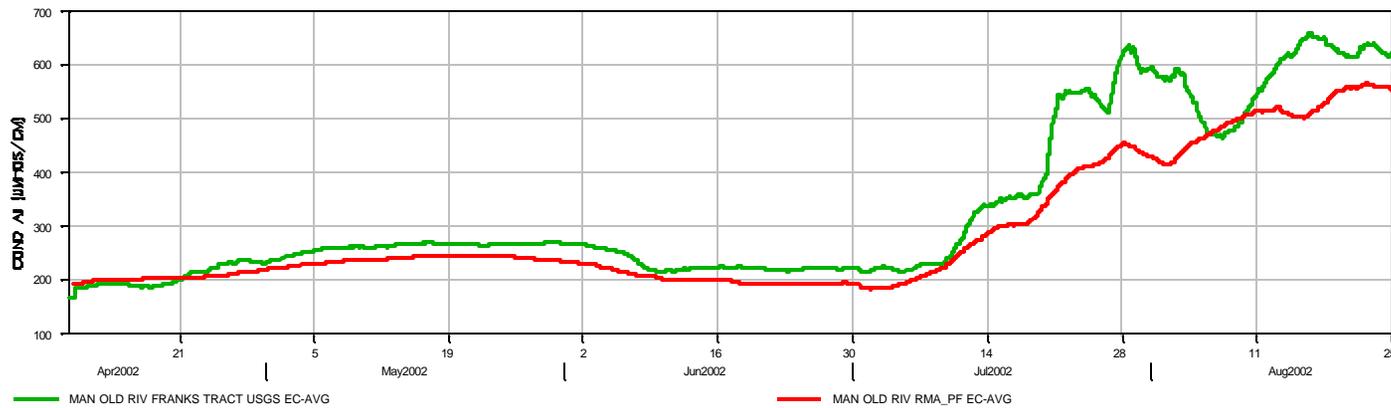
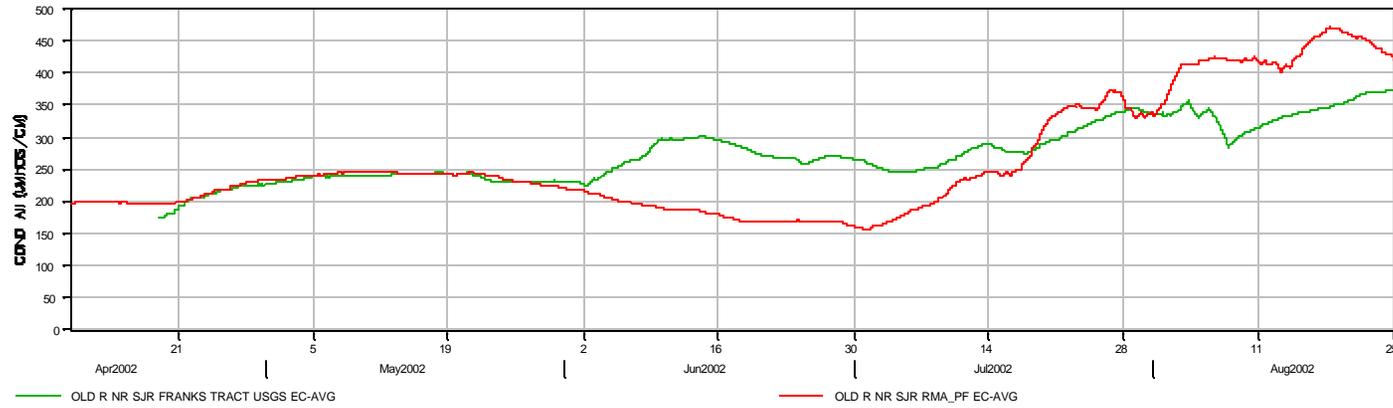


Figure 6-23 Tidally averaged Delta EC comparisons for April – August, 2002.

### Old River near SJR



### Mokelumne near SJR

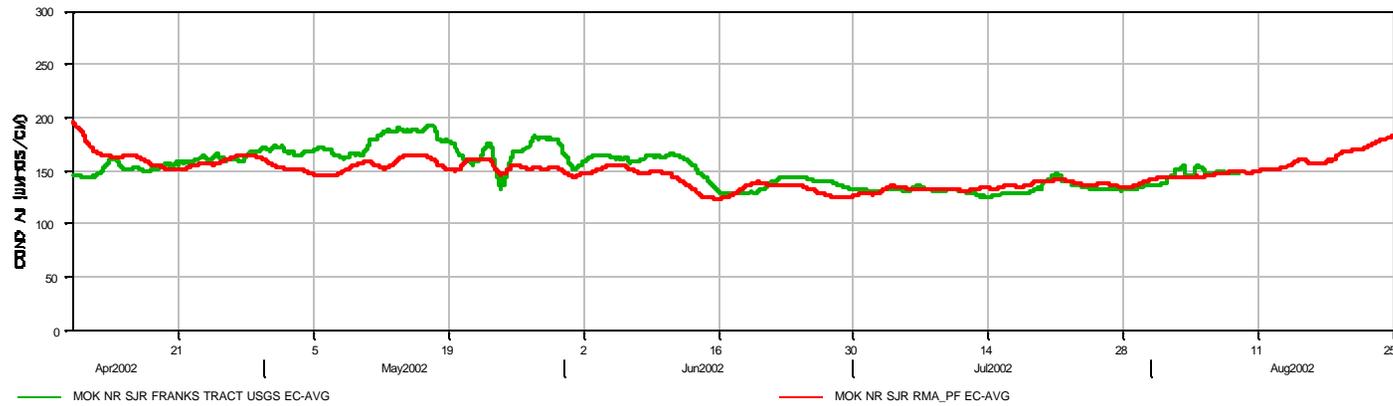
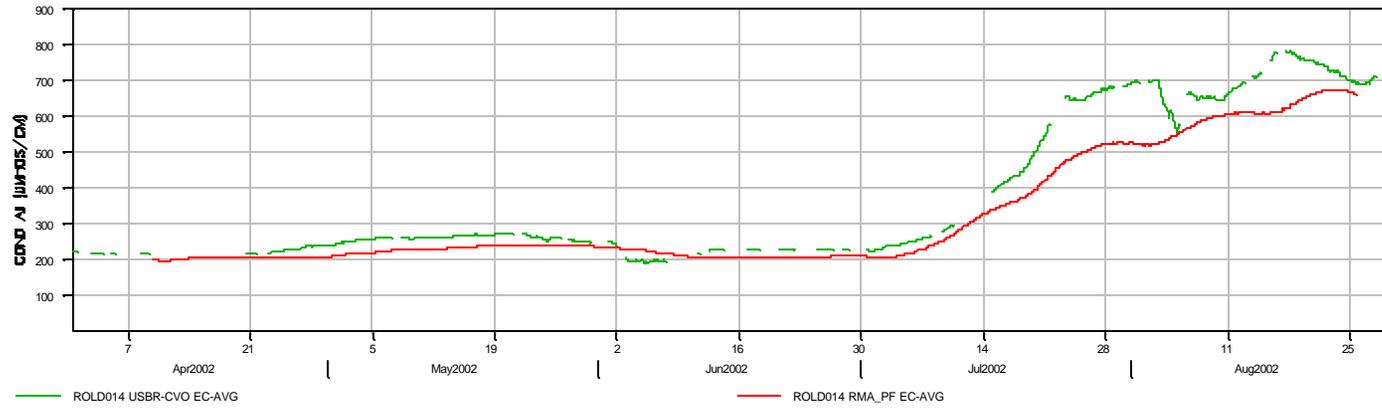


Figure 6-24 Tidally averaged Delta EC comparisons for April – August, 2002.

### ROLD014



### RMID023 ( not tidally averaged)

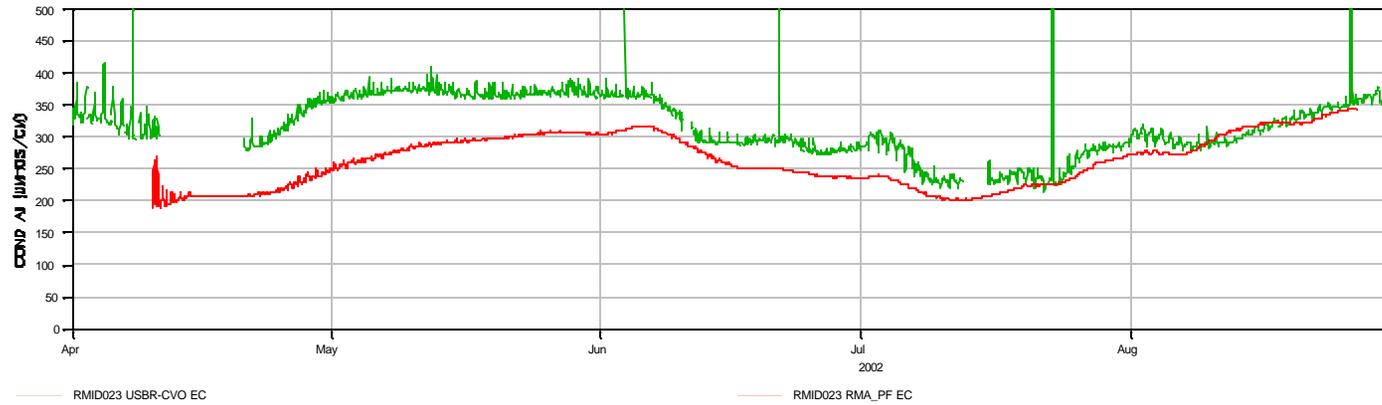
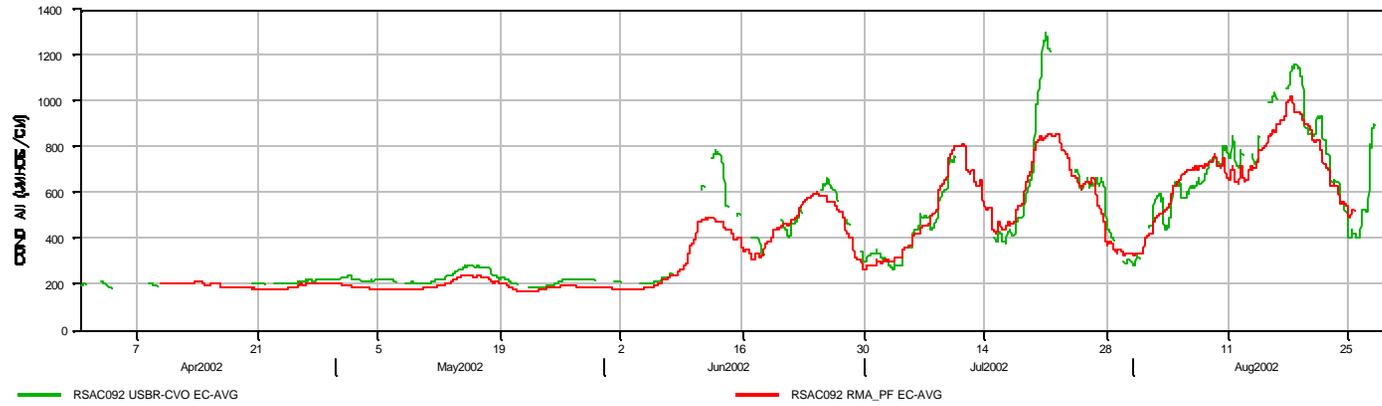


Figure 6-25 Delta EC comparisons for April – August, 2002 (ROLD014 is tidally averaged).

### RSAC092



### RSAC101

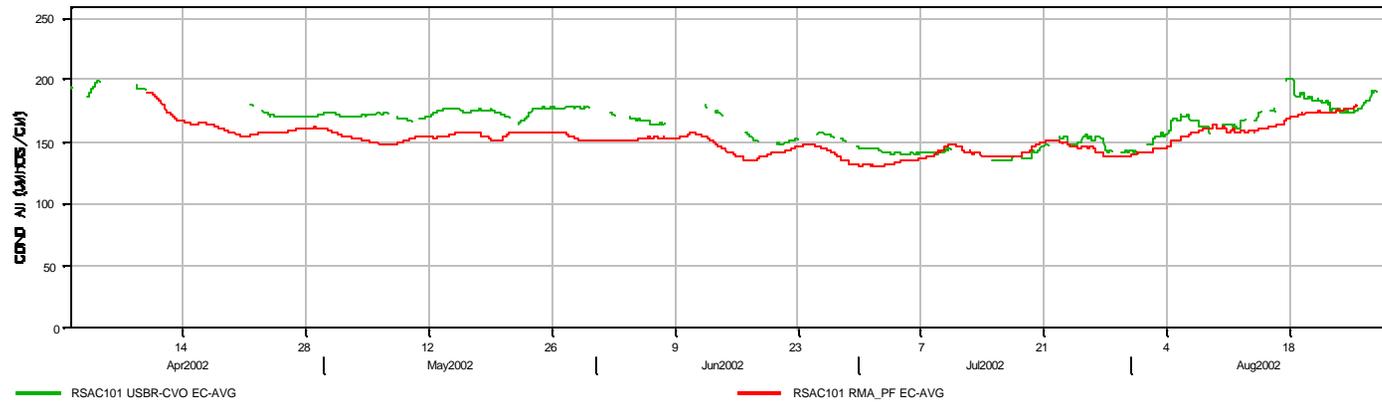


Figure 6-26 Tidally averaged Delta EC comparisons for April – August, 2002.