State of California
The Resources Agency
Department of Water Resources
Bay-Delta Office

METHODOLOGY FOR FLOW AND SALINITY ESTIMATES IN THE SACRAMENTO-SAN JOAQUIN DELTA AND SUISUN MARSH

TWENTY-SIXTH ANNUAL PROGRESS REPORT TO THE STATE WATER RESOURCES CONTROL BOARD
in Accordance with Water Right Decisions 1485 and 1641

October 2005

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Governor
State of California

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Secretary for Resources
The Resources Agency

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FOREWORD

This is the 26th annual progress report of the California Department of Water Resources' San Francisco Bay-Delta Evaluation Program, which is carried out by the Delta Modeling Section. This report is submitted annually by the Section to the California State Water Resources Control Board pursuant to its Water Right Decision 1485, Term 9, which is still active pursuant to its Water Right Decision 1641, Term 8.

It documents progress in the development and enhancement of the Bay-Delta Office's Delta Modeling Section's and Division of Environmental Service's Suisun Marsh Planning Section's computer models and reports the latest findings of studies conducted as part of the program. This report was compiled by Michael Mierzwa, with assistance from Jane Schafer-Kramer and Marilee Talley, under the direction of Bob Suits, Senior Engineer, and Tara Smith, program manager for the Bay-Delta Evaluation Program.

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1 Introduction

Over the past 12 years, the Delta Modeling Section of the California Department of Water Resources' Bay-Delta Office has been developing and enhancing the Delta Simulation Model Version 2 (DSM2), the tools used to support DSM2 modeling, and other Delta flow and water quality estimation tools. The following are brief summaries of work that was conducted during the past year. The names of contributing authors are in parentheses.

Chapter 2 – Using Dye-Injection Study to Revise DSM2-SJR Geometry

Work related to the San Joaquin River Dissolved Oxygen Total Maximum Daily Load Technical Work Group revealed that simulated travel times in the DSM2 San Joaquin River extension were significantly greater than observed travel times. To improve the DSM2-SJR, the irregular cross sections and channel roughness between Bear Creek and Vernalis were modified to more accurately represent the local bathymetry and to simulate travel times approximating the observed dye study travel times. After the revisions, DSM2-SJR accuracy was verified in simulating flow, water levels, and salinity.
(Jim Wilde)

Chapter 3 – Jones Tract 2004 Levee Break DSM2 Simulation

Following the June 3, 2004, Jones Tract Levee Break, the Department used DSM2 to forecast both hydrodynamic and water quality impacts at various Delta locations in response to the flooding. From June through November 2004, the Municipal Water Quality Investigations (MWQI) Program of the Department's Office of Water Quality collected water quality field data in Upper and Lower Jones Tracts. The DSM2 historical simulation was updated for 2004, and the DSM2-QUAL algorithm, which is used to simulate increases in organic carbon concentrations due to the flooding of peat soil-based islands, was applied to Jones Tract. This chapter discusses the methodology used to simulate the Jones Tract Levee Break and compares the modeled hydrodynamic, electrical conductivity, and dissolved organic carbon results to MWQI field data.
(*Mierzwa and Suits*)

Chapter 4 – Sensitivity of DSM2 Temperature Simulations to Time Step Size

The San Joaquin River Dissolved Oxygen Total Maximum Daily Load Technical Working Group is using DSM2-QUAL to characterize the transformation and fate of algae and other oxygen-demanding materials in the San Joaquin River between their sources in the watershed and the Stockton Deep Water Ship Channel. The DSM2-QUAL modules for simulating dissolved oxygen and temperature, in addition to the DSM2-SJR extension discussed in Chapter 2, were used to assess the impact of San Joaquin River water on the Deep Water Ship Channel. The Technical Working Group raised questions regarding the range of time steps that can be used in the simulations. In response, a series of DSM2 temperature simulations were conducted downstream of Vernalis to determine the sensitivity of the results to different time steps. This chapter presents the results of these studies.
(*Hari Rajbhandari*)

Chapter 5 – Estimation of Electrical Conductivity at Martinez for Sea Level Rise Conditions

CALSIM and DSM2 are being used to investigate some potential impacts to water supply and quality in the Delta due to long-term climate change and sea level rise. In order to study these sorts of long-term phenomena, it is necessary to develop appropriate water level and salinity ocean boundary conditions for DSM2. DSM2's downstream boundary at Martinez is not located at the ocean. Therefore, it is necessary to come up with a way to account for the possible increase in the amount of salinity (represented as electrical conductivity in DSM2) that enters the Delta due to increases in sea level. Two different methods are presented for estimating electrical conductivity for sea level rise-based DSM2 simulations.
(*Jamie Anderson and Aaron Miller*)

Chapter 6 – Fingerprinting: Clarifications and Recent Applications

Over the past few years, DSM2 has increasingly been used to determine the sources of water or constituents at specified locations in the Delta, a procedure known as fingerprinting. Knowing the source of water at a given location can be important when making assumptions about constituents that cannot be directly simulated or for better understanding hydrodynamic mixing-based processes in the Delta. This chapter expands previous descriptions of DSM2 fingerprinting methodologies and reviews a few recent practical fingerprinting applications.
(*Jamie Anderson and Jim Wilde*)

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

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Chapter 2:
Using Dye-Injection Study to Revise DSM2-SJR Geometry

Author: Jim Wilde

2 Using Dye-Injection Study to Revise DSM2-SJR Geometry

2.1 Introduction

Channel descriptions in the San Joaquin River extension of the Delta Simulation Model Version 2 (DSM2-SJR), spanning from Vernalis upstream to Bear Creek, were refined after closer examination of bathymetry data. To include field-measured depths in determining a representative cross section, distance was reduced upstream and downstream of a cross section. Irregular cross sections in DSM2 were generally reduced in width and cross-sectional area. This change reduced the modeled travel time in this reach of the San Joaquin River, bringing it closer to an actual dye-tracer study. Original estimates for Manning's *n* values were also modified to further improve the accuracy of modeled travel time and better reproduce water levels.

2.2 Background

The Stockton Deep Water Ship Channel Total Maximum Daily Load Dissolved Oxygen Modeling Team is using DSM2-SJR to model dissolved oxygen at Vernalis. In evaluating the model for this purpose, Brown and Huber (2004) used a 1994 dye-tracer study (Kratzer and Biagtan, 1997) to check travel times down the San Joaquin River. Plugs of high-concentration electrical conductivity (EC) were input to the model near the dye-injection input locations in the field study. The modeled travel time was found to be approximately 50% longer than that observed in the field. By examining the irregular cross sections in DSM2, staff at Jones and Stokes noticed that DSM2-SJR channels near Patterson were too wide. Although past modeling of EC to estimate salinity at the lower boundary of the DSM2-SJR grid had been adequate for model calibration (Pate, 2001), the error in travel time noted by Jones and Stokes was thought to be a problem when modeling non-conservative constituents such as dissolved oxygen, particularly during lower flows. As a consequence, the Department of Water Resources' Delta Modeling Section investigated modifying the grid in the San Joaquin River upstream of Vernalis.

2.3 DSM2 Simulation of Dye-Tracer Studies

DSM2-SJR was first used to repeat Jones and Stokes' simulation of historical conditions during two dye-injection studies in 1994. Historical flow and EC had already been modeled for the period of 1990 through water year 1999 (Wilde, 2004). Given the data presented in the Kratzer and Biagtan (1997) study, the dye-injection studies of February 9 and June 20, 1994, were found to be appropriate to be simulated. The actual dye-tracer injection locations were in streams flowing into the San Joaquin River. The February location was in the Merced River at River Road, and the June location was in Salt Slough at Highway 165. DSM2-SJR does not model the tributaries of the San Joaquin River. For simulation purposes slugs of high EC concentrations were injected at the respective stream confluences with the San Joaquin River (Figure 2.1) at the estimated time when the dye-tracer plugs reached the confluences (Kratzer and Biagtan, 1997).

Simulated EC concentrations were output at locations monitored in the dye-tracer studies. The estimated travel times to Vernalis are shown for comparison (Figures 2.2 and 2.3). For the original DSM2-SJR grid, the estimated travel times were significantly longer than the field study, agreeing with the findings by Jones and Stokes. In the February study during an average flow of 2,800 cubic feet per second (cfs), the DSM2-SJR estimated travel time from the Merced River to Vernalis was 50 hours, but the estimated travel time in the field was approximately 38 hours. For the June study during an average flow of 1,000 cfs, the DSM2-SJR estimated travel time from Salt Slough to Vernalis was 106 hours, but the estimated travel time in the field was approximately 74 hours. The modeled travel times in February and June of 1994 were, respectively, 32% and 43% longer than those indicated by field measurements. These differences were considered mandates for refining the DSM2-SJR grid.

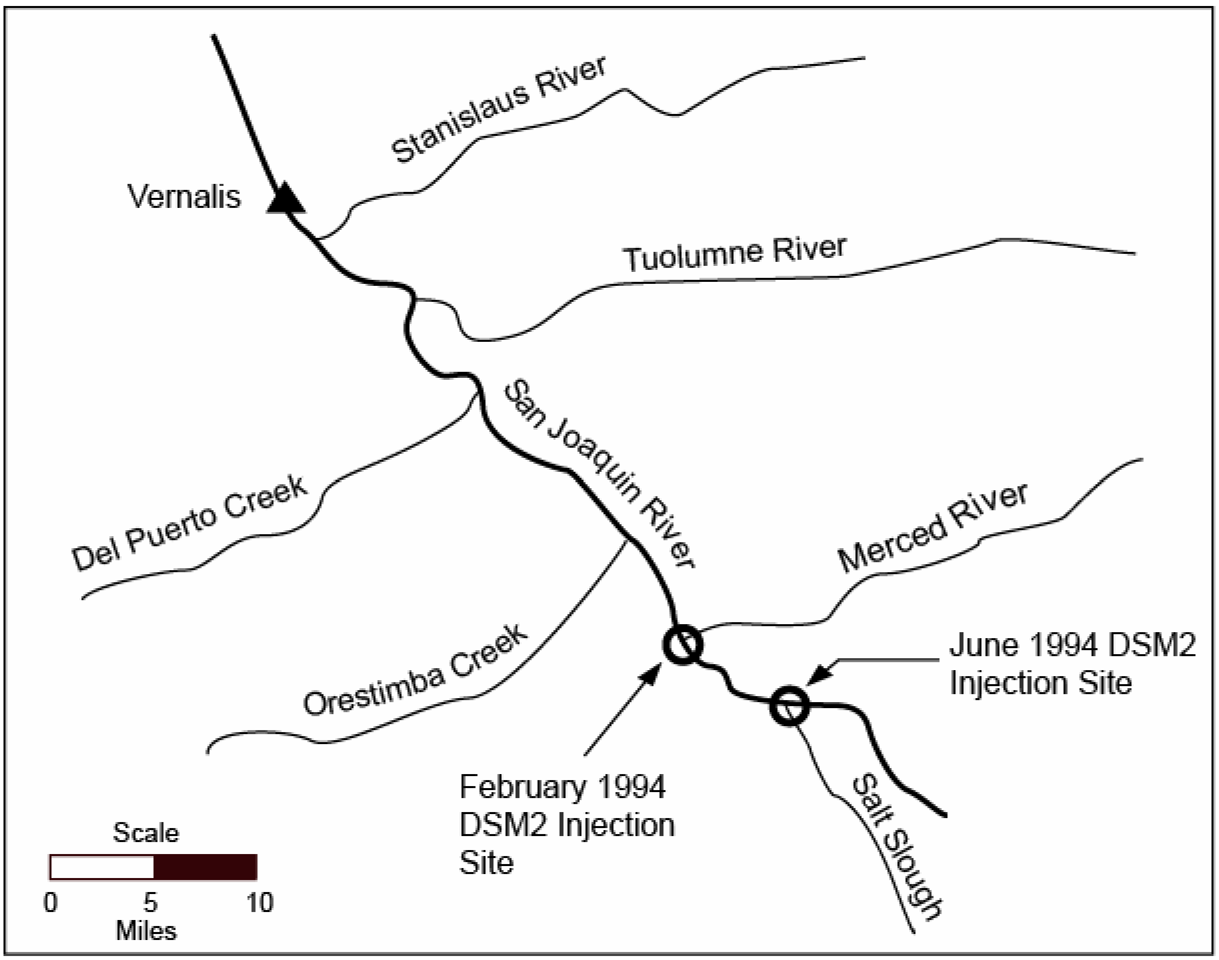

Figure 2.1: Locations of DSM2 Injection Sites to Simulate February and June 1994 Dye-Injection Studies.

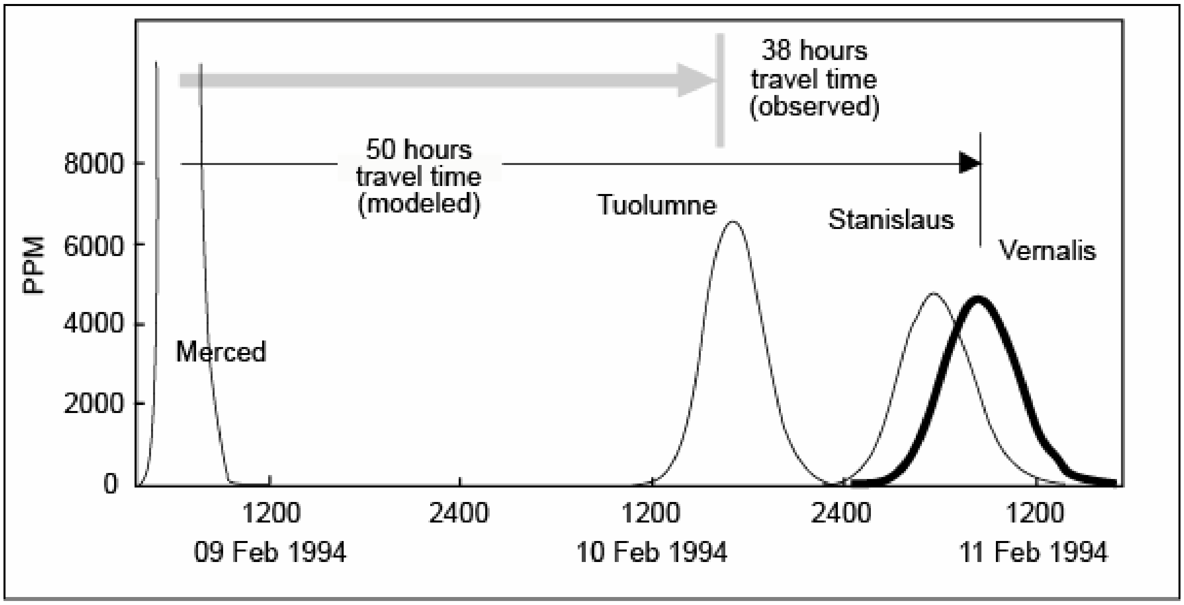

Figure 2.2: Original DSM2-SJR Modeled EC along the San Joaquin River during Simulation of Dye-Injection Study in February of 1994 (Model Travel Time is 50 Hours Compared to Observed 38 Hours).

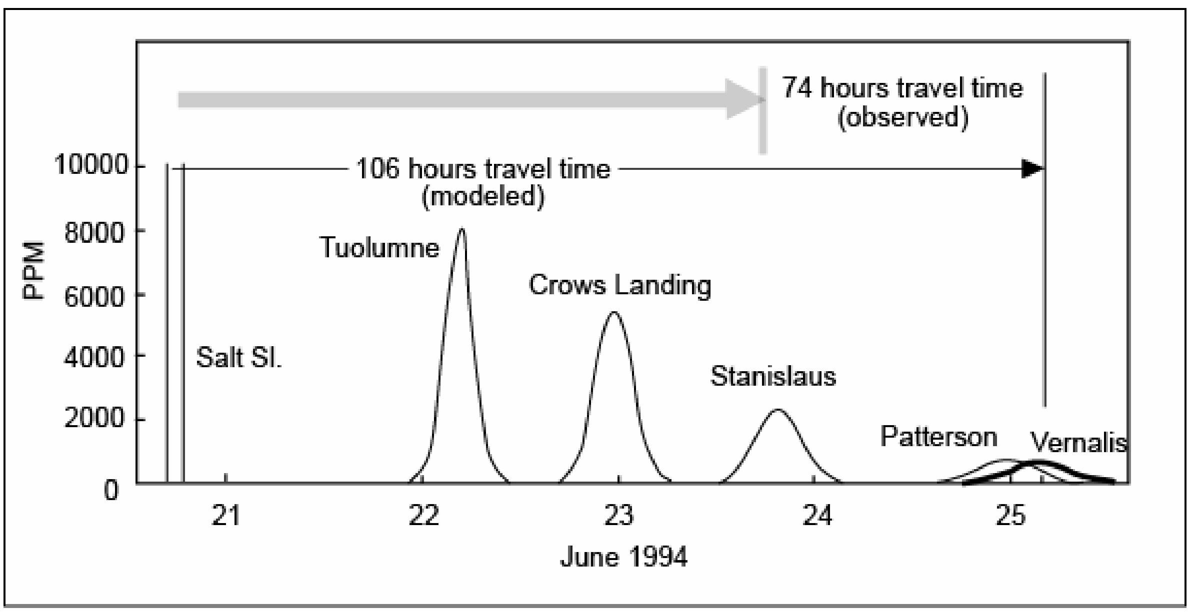

Figure 2.3: Original DSM2-SJR Modeled EC along the San Joaquin River during Simulation of Dye-Injection Study in June of 1994 (Model Travel Time is 74 Hours Compared to Observed 106 Hours).

2.4 Irregular Cross Section Investigation and Adjustments

In order to better replicate hydraulic conditions, the river geometry in DSM2-SJR was re-examined. The Cross Section Development Program (CSDP) had been used to develop the original irregular cross sections in the San Joaquin River upstream of Vernalis, using the bathymetry gathered from the US Army Corps of Engineers (Tom, 1998, Pate, 2001). For any given cross section, CSDP requires a distance upstream and downstream of the cross section to query and return bathymetry data. The user then fits a single cross section to the data. The upstream and downstream distances generated in CSDP and used in the DSM2-SJR reach were judged to be too large and to introduce bias in channel width. CSDP used meandering, hand-drawn centerlines as the reference datum to project the elevation data in a cross-sectional view. If the centerline does not follow the true center of the channel, a wide sampling of the elevation data may yield a misrepresentation of the bathymetry because elevation data points may be too scattered. This results in the channel width being too large. Figure 2.4 shows a cross-section display at location 625_1, just upstream of Patterson, with elevation data displayed 1,000 feet upstream and downstream of the cross section. The resulting cross-sectional width approaches 700 feet. A smaller cross-sectional width results by reducing the display thickness from the default value of 1,000 feet. Figure 2.5 shows an example of a thickness set at 300 feet at the same location. The cross section now displays a more representative channel width that is less than 200 feet. Where adjustment to an irregular cross section was warranted, sampling of bathymetry data were taken based upon varying distances from the cross section to derive an average representation at the location of the adjustment.

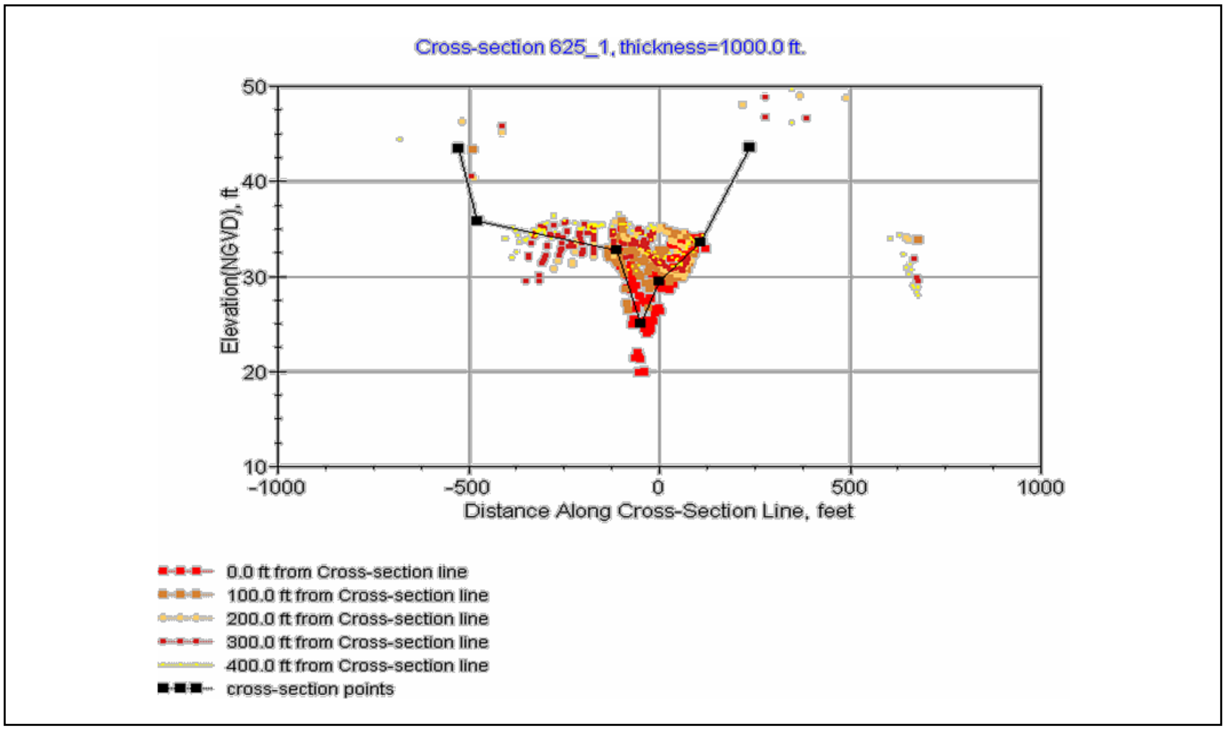

Figure 2.4: Irregular Cross Section with a Thickness of 1,000 Feet and a Misrepresented Width of Approximately 700 feet at Channel Location 625_1.

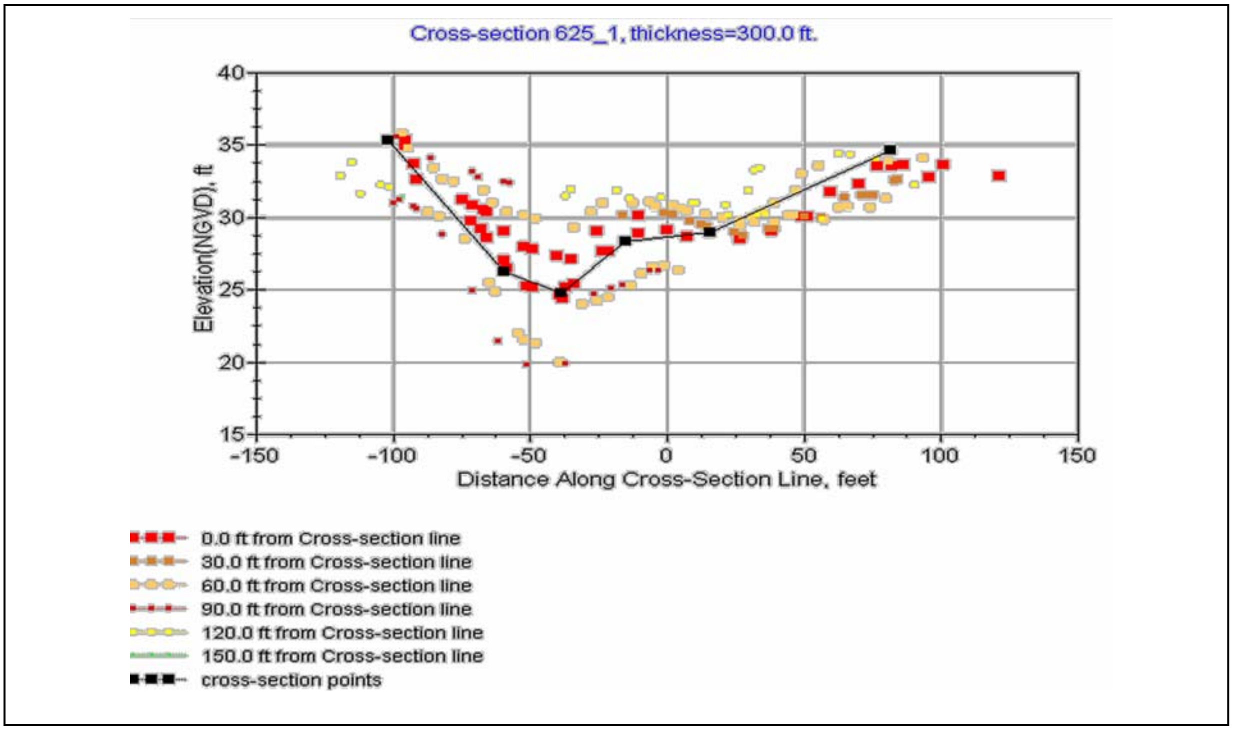

Figure 2.5: Irregular Cross Section with a Thickness of 300 Feet and a More Representative Width of Approximately 180 Feet at Channel Location 625_1.

The cross sections in the San Joaquin River between the Tuolumne and Stanislaus rivers were also adjusted to smooth the channel bottom by averaging unrepresentative and unusually low or high invert elevations that may form unrealistically large pools and riffles. Because the simulated travel time after the adjustment for widths was much longer than the field data indicated, the channel bottoms between the Tuolumne and the Stanislaus rivers were adjusted to induce lower velocities. As shown in Figure 2.6 the original DSM2 bottom geometry in the San Joaquin River upstream of Vernalis widely fluctuated, so adjustments were made within reason of the given elevation data (Figure 2.7).

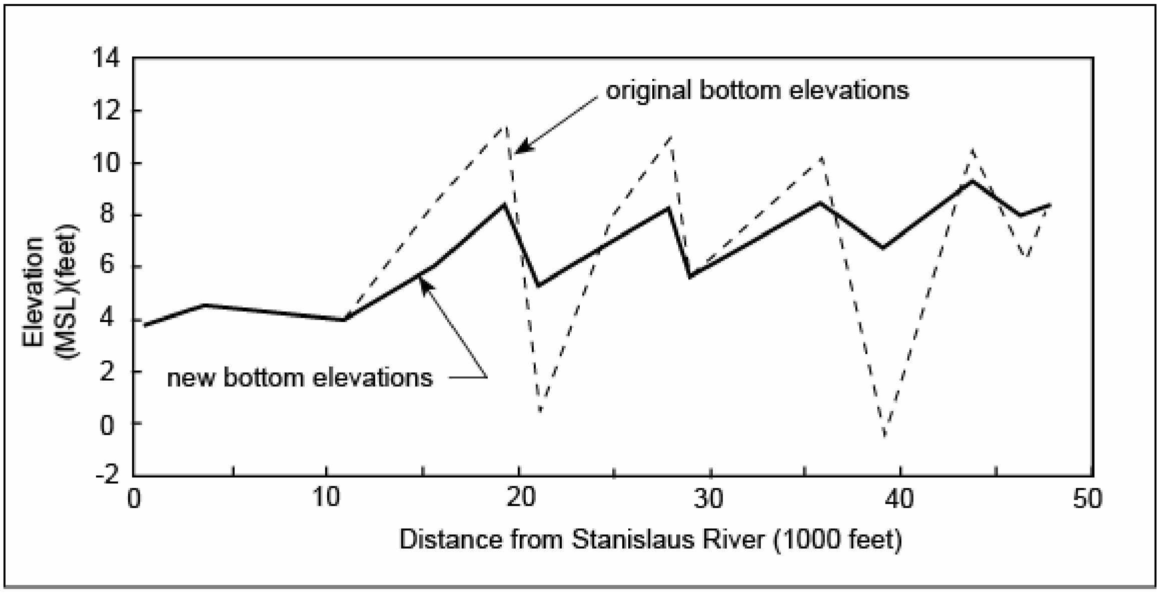

Figure 2.6: Thalwegs Constructed from the Irregular Cross Sections between the Stanislaus River Confluence and the Tuolumne River Confluence.

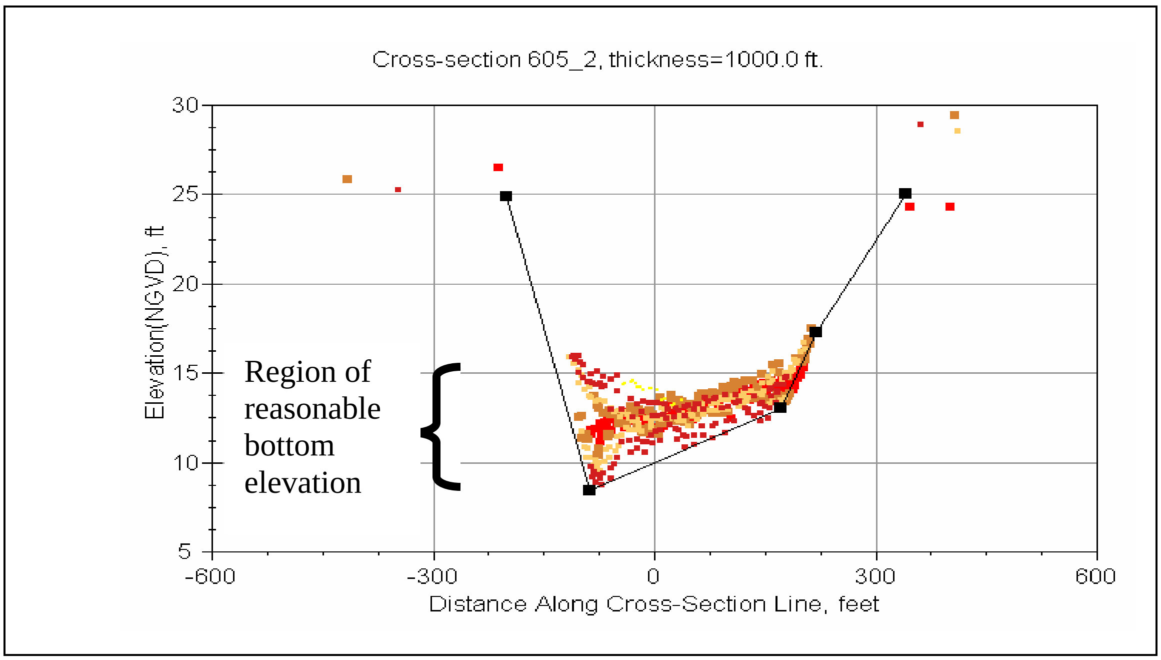

Figure 2.7: Irregular Cross Section along the San Joaquin River at a Distance of 19,330 Feet upstream of the Stanislaus River Confluence (Here the Bottom Elevation Was Lowered from 11.5 Feet to 8.5 Feet MSL).

After local widths and bottom elevations for cross sections were adjusted, a simulation of flow down the San Joaquin River produced noticeable improvements to travel times (Figures 2.8 and 2.9). The modeled February injection produced a travel time of 41 hours from the Merced River confluence to Vernalis. The modeled June injection produced a travel time of 88 hours from the Salt Slough confluence to Vernalis. These times are respectively 11% and 19% greater than the field data. Further refinements of the irregular cross sections to improve the travel times, such as smoothing the channel bottom in other regions, were attempted but were not effective and, therefore, not used.

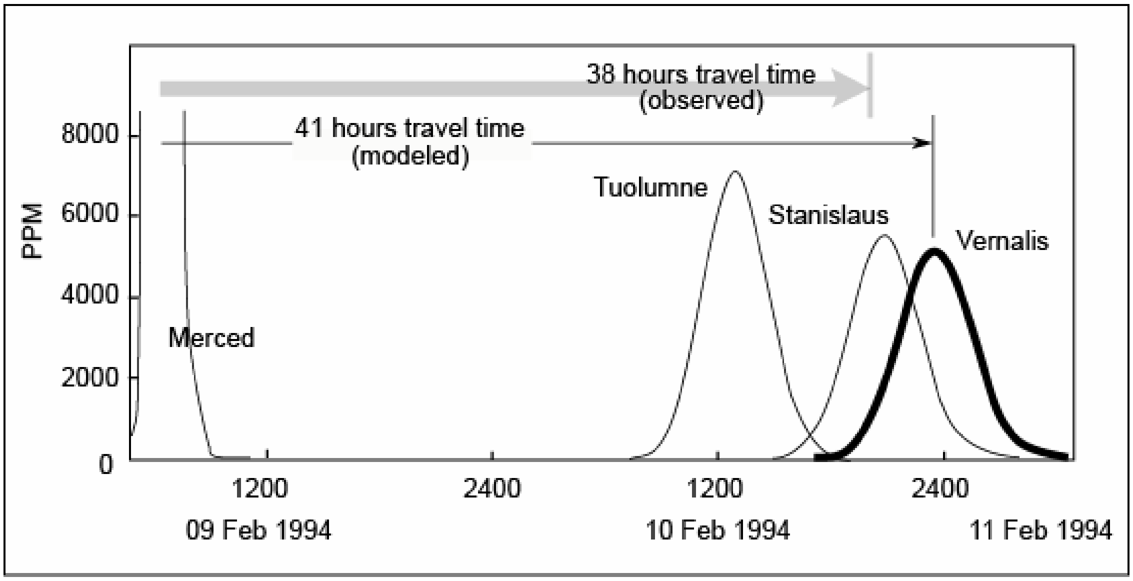

Figure 2.8: Travel Time in February with Final Adjustments to the Irregular Cross Sections.

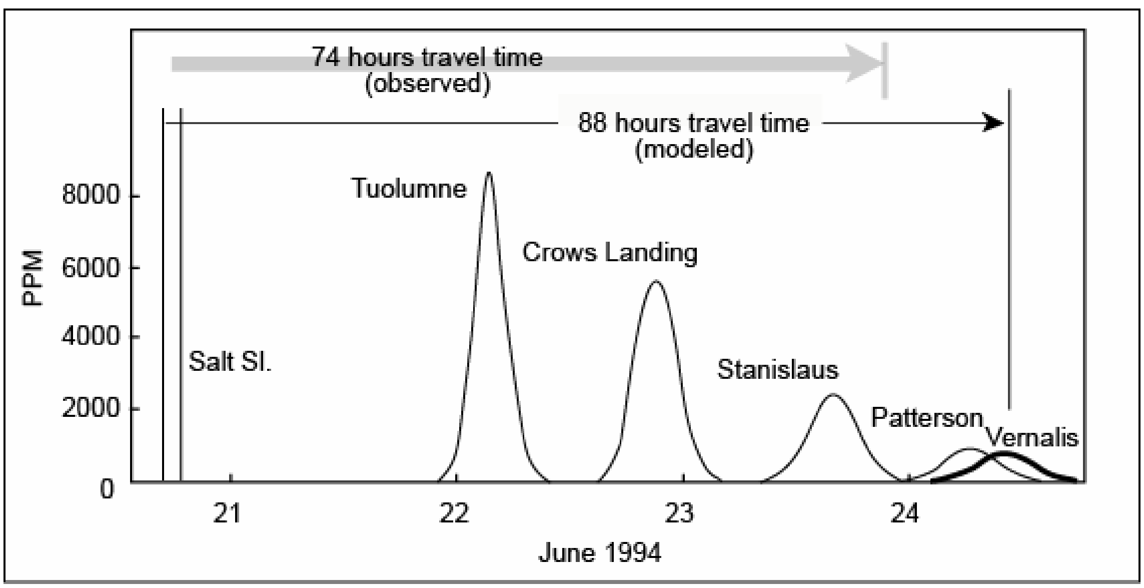

Figure 2.9: Travel Time in June with Final Adjustments to the Irregular Cross Sections.

2.5 Manning's *n* Adjustment

The DSM2-SJR channel description was further modified by adjusting the Manning's *n* values used in DSM2 to represent channel roughness and friction. The modification was made to better reproduce observed travel times during the dye-injection studies. The calibrated version of

DSM2-SJR assumed only two values for Manning's *n*: a value of 0.035 from the upper boundary of the grid near Stevinson down to the San Joaquin River near Patterson, and a value of 0.030 from Patterson to Vernalis.

Manning's *n* values were refined via experimentation to better match the estimated dye-tracer travel time to and from various locations down the San Joaquin River. Locations included Hills Ferry, Crows Landing, Patterson, the Tuolumne River confluence, the Stanislaus River confluence, and Vernalis. The Manning's *n* values that were considered most effective ranged from 0.024 to 0.037 and were applied as shown in Figure 2.10. The values are constant between the individual locations of the San Joaquin River: Stevinson to Salt Slough, Salt Slough to the Merced River, the Merced River to Crows Landing, Crows Landing to just above Patterson, just above Patterson to just below Patterson, just below Patterson to the Tuolumne River, the Tuolumne River to the Stanislaus River, and the Stanislaus River to Vernalis. The Manning's *n* value of 0.035 around Patterson was required for better stage agreement with data at the Patterson station.

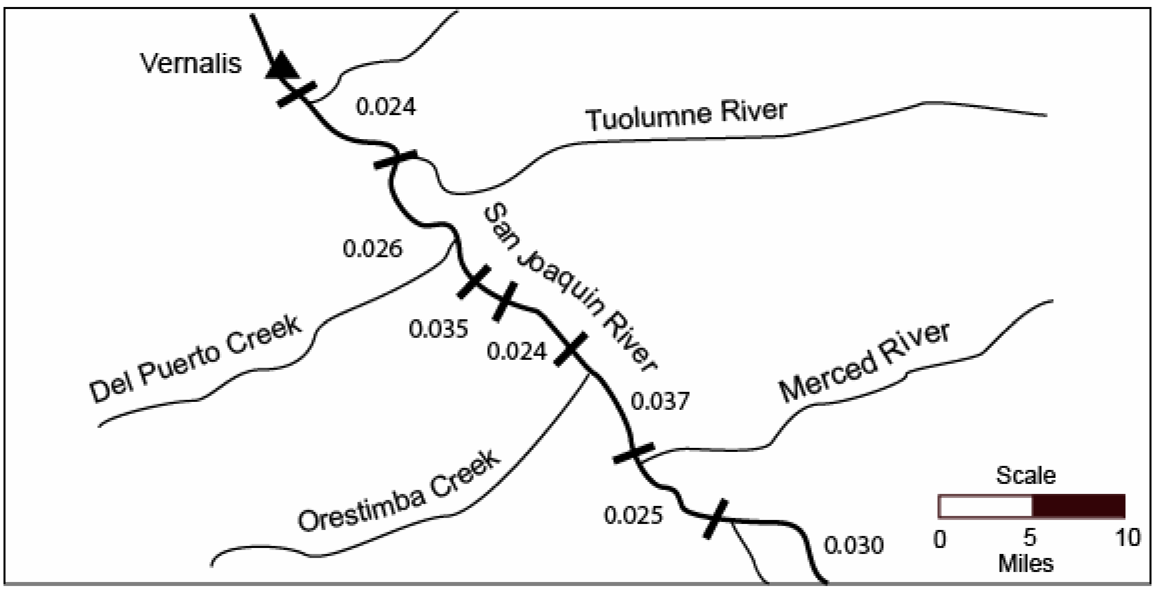

Figure 2.10: New Manning's *n* Values Used in DSM2-SJR.

The travel time of the DSM2 injections considerably improved using the adjusted irregular cross sections and the new Manning's *n* values. As shown in Figure 2.11, the observed February travel time from the Merced River to Vernalis was approximately 38 hours compared to the model's initial travel time of 37 hours. The June injection produced an observed 74-hour travel time from the Salt Slough confluence to Vernalis, compared to the model's initial travel time of 75 hours (Figure 2.12). These new simulated travel times more closely reproduce the respective field estimates of 38 hours and 74 hours.

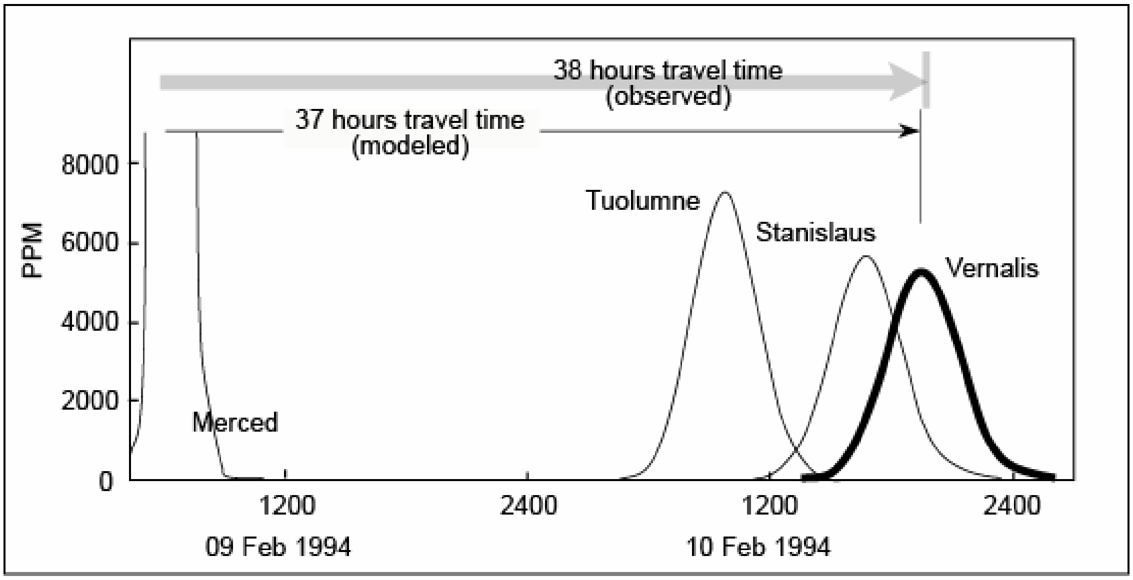

Figure 2.11: Travel Time in February with Final Adjustments to the Grid and Manning's *n* Values.

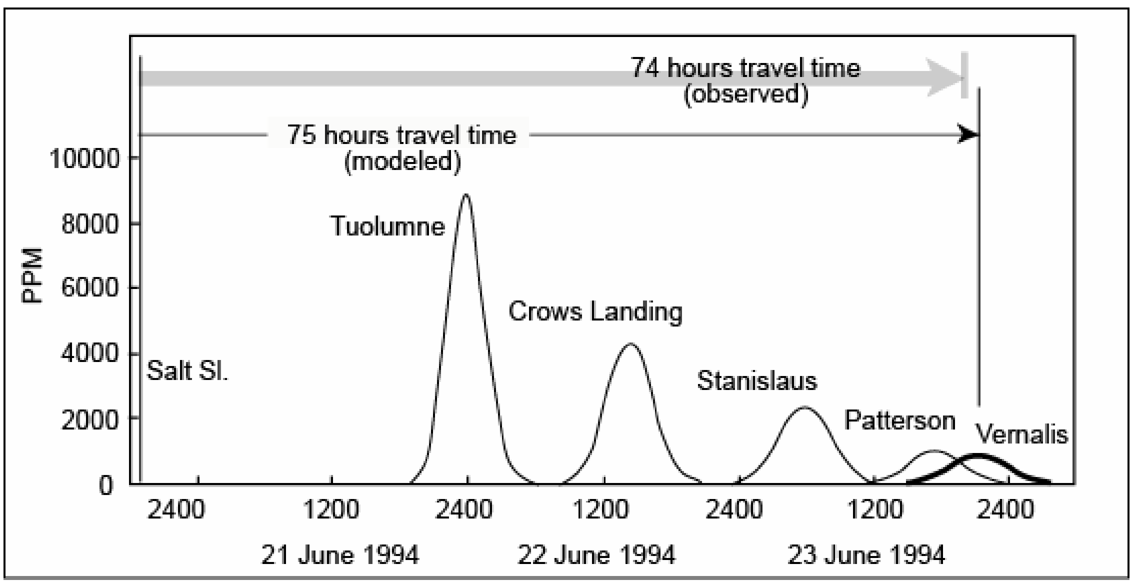

Figure 2.12: Travel Time in June with Final Adjustments to the Grid and Manning's *n* Values.

2.6 General Effect on EC and Flow

The modifications generally changed the timing of EC and flow values at Vernalis but did not greatly affect the magnitudes or overall trends. The most noticeable change in EC was a shift of a day earlier to changes in output concentration (Figure 2.13). The simulated travel time of changes in EC was decreased by about a day from Mud and Salt Sloughs, where a large portion of the San Joaquin River salt load is derived, to Vernalis. The flow at Vernalis also was shifted, but by a lesser degree than EC. As shown in Figure 2.14, the shift was up to half a day earlier depending on the relative volume of water entering at the Stanislaus River confluence. The effect to stage at Vernalis was minimal due to the changes in Manning's *n*.

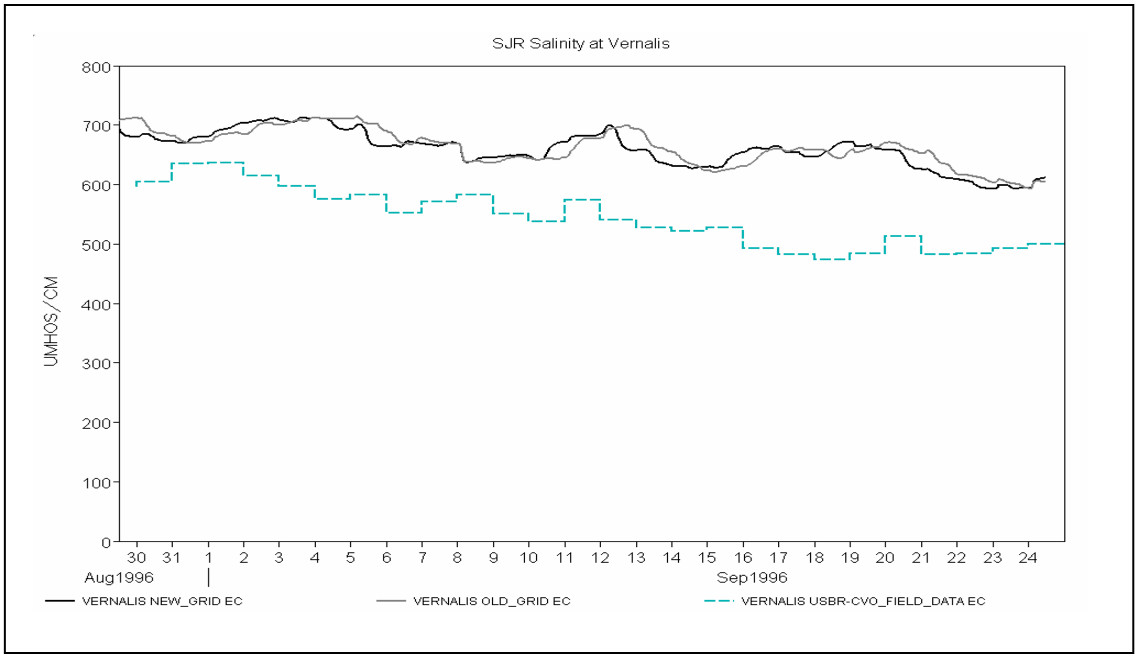

Figure 2.13: Example of Modeled EC at Vernalis before the Modifications (OLD_GRID) Versus after the Modifications (NEW_GRID).

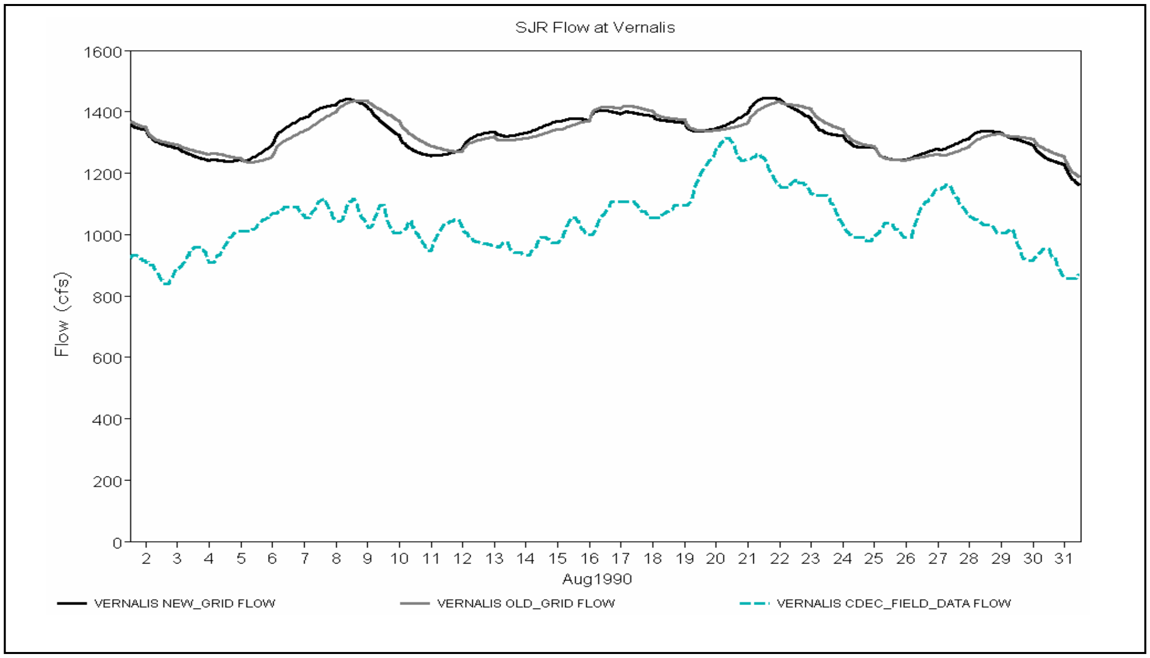

Figure 2.14: Example of Modeled Flow at Vernalis before the Modifications (OLD_GRID) Versus after the Modifications (NEW_GRID).

2.7 Summary

Kratzer and Biagtan (1997) estimated travel times for two dye-tracer studies performed in February and June 1994. Their work was the basis for a mini-recalibration of DSM2-SJR. Using the model as originally calibrated by the 1997 to 1999 period, travel times simulated in an attempt to replicate the 1994 dye-tracer studies were 132% and 143% of the field results. To enhance DSM2-SJR's appropriateness for non-conservative constituent estimations, the grid and applied Manning's *n* values were refined to better calculate hydrodynamics down the San Joaquin River from the Salt Slough confluence to near Vernalis. Modification to the irregular cross sections, bottom elevations between the Stanislaus and Tuolumne River confluences, and Manning's *n* values were applied to better simulate the travel times indicated by the 1994 dye-injection studies. As a result, DSM2-SJR simulations of flow in the San Joaquin River upstream of Vernalis improved.

2.8 References

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

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Chapter 3:
Jones Tract 2004 Levee Break DSM2 Simulation

Author: Michael Mierzwa and Bob Suits

3 Jones Tract 2004 Levee Break DSM2 Simulation

3.1 Introduction

On June 3, 2004, the Upper Jones Tract levee near Woodward Island failed, resulting in the flooding of both Upper and Lower Jones Tracts. Because flooded peat soils like those found on Upper and Lower Jones Tracts can be significant sources of organic carbon, Delta Simulation Model II (DSM2) was used to make short- and long-term water quality forecasts. Two- to four-week long, short-term forecasts made by the California Department of Water Resources' Division of Operations and Maintenance (O&M) focused on the hydrodynamic and electrical conductivity impacts related to the Jones Tract levee break and pump-off operations. Long-term forecasts, conducted by DWR's Delta Modeling Section, focused more on projecting the organic carbon concentrations at the urban intakes caused by the pump-off operations through the rest of 2004 (Mierzwa, 2004, Mierzwa et al., 2004). For these long-term forecasts, the representation of Upper and Lower Jones Tracts was refined by calibrating the timing of the break, the coefficient of flow through the breach, the scheduled pump-off of the two islands, and the organic carbon growth rate. Four of these DSM2 calibration scenarios are presented in this chapter. The final results of this calibration were incorporated into the DSM2 2004 simulation of south Delta hydrodynamics (Suits et al., 2005).

3.2 Conditions in the Delta Prior to the Levee Break

October 2003 through September 2004 was classified as a "Below Normal" water year type. However, calendar year 2004 Net Delta Outflow was characterized by extremely high flows in March and then low flows through the rest of the year. NDO can be used as a measure of water availability in the Delta. As shown in Figure 3.1, NDO was higher in March 2004 (around calendar day 60) than in March 1993 and 2003 despite the fact that 1993 and 2003 were both classified as "Above Normal" years. The high NDO of March 2004 caused low salinity concentrations in the Delta through early April. In mid-April San Joaquin River flows were increased, and the combined State Water Project (SWP) and Central Valley Project (CVP) exports were decreased as part of the Vernalis Adaptive Management Plan (VAMP). This helped maintain low salinity concentrations in much of the Delta. Two of the south Delta temporary barriers and the head of Old River fish protection barrier were installed in mid-April. Although San Joaquin River flows were decreased in mid-May, San Joaquin River electrical conductivity (EC) at Vernalis doubled in the course of a few weeks. During this same time, the head of Old River barrier was removed, thus allowing San Joaquin River water to travel through Grant Line Canal to the SWP and CVP export facilities. By the time the Upper Jones Tract levee failed (calendar day 155), salinity in the Delta was beginning to increase.

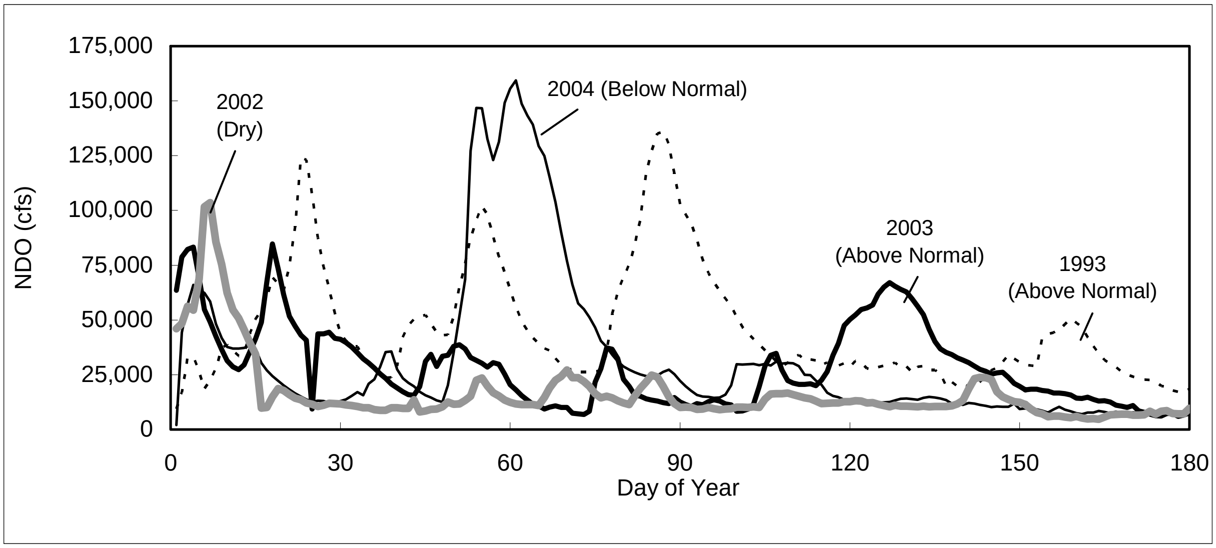

Figure 3.1: Selected Net Delta Outflows by Year and Water Year Type.

3.3 Timeline of Jones Tract 2004 Events

The hydrodynamic response of the Delta to the flooding of Jones Tract was influenced by four key events (see Table 3.1). When the Upper Jones Tract levee broke, between 150 and 200 thousand acre-feet (taf) of water flooded both Upper and Lower Jones Tracts in less than a week. The break occurred during a spring tide (a tide with maximum range in stage) as central Delta water levels were dropping from the higher-high to the lower-low tide. As Upper Jones Tract filled, water moved to Lower Jones Tract via an access road under the Santa Fe Railroad. Once both islands were filled, water moved in and out of Upper Jones Tract based on changes in Delta water levels due to the tide. Lower Jones Tract was more isolated than Upper Jones Tract. This period of tidal exchange between Upper Jones Tract and the Middle River continued until late June, when enough material had been deposited in the levee breach to effectively restrict the majority of the flow in and out of Upper Jones Tract. When the levee breach was first closed, the organic carbon-rich water on both Jones Tract islands was isolated from the Delta. However, when the pump-off operations began on July 12, the high organic carbon concentration water on the island was again mixed with the lower concentration Middle River water near Santa Fe Cut. The pump-off operations continued until December 18.

Table 3.1: Estimated DSM2 Timeline of Jones Tract 2004 Events.

Levee Break	June 3 6:51 PST
Closure of Levee Breach	June 30 12:00 PST
Start of Major Pump-off Operations	July 12 00:00 PST
End of Major Pump-off Operations	December 18 00:00 PST

In DSM2 the levee break and repair were assumed to be instantaneous in order to simplify the calibration process. The Department was not able to install accurate flow meters in the pipes used to remove water from the islands, thus it was necessary to estimate the pump-off flow rates, which for the purpose of modeling were assumed to be daily average flows. Because DSM2 does not account for daylight-saving time, the reported time of the breach, 7:50 a.m. Pacific Daylight Time (DWR, 2004), was converted to Pacific Standard Time. The start times of the other three events were estimated.

3.4 Representation of Jones Tract in DSM2

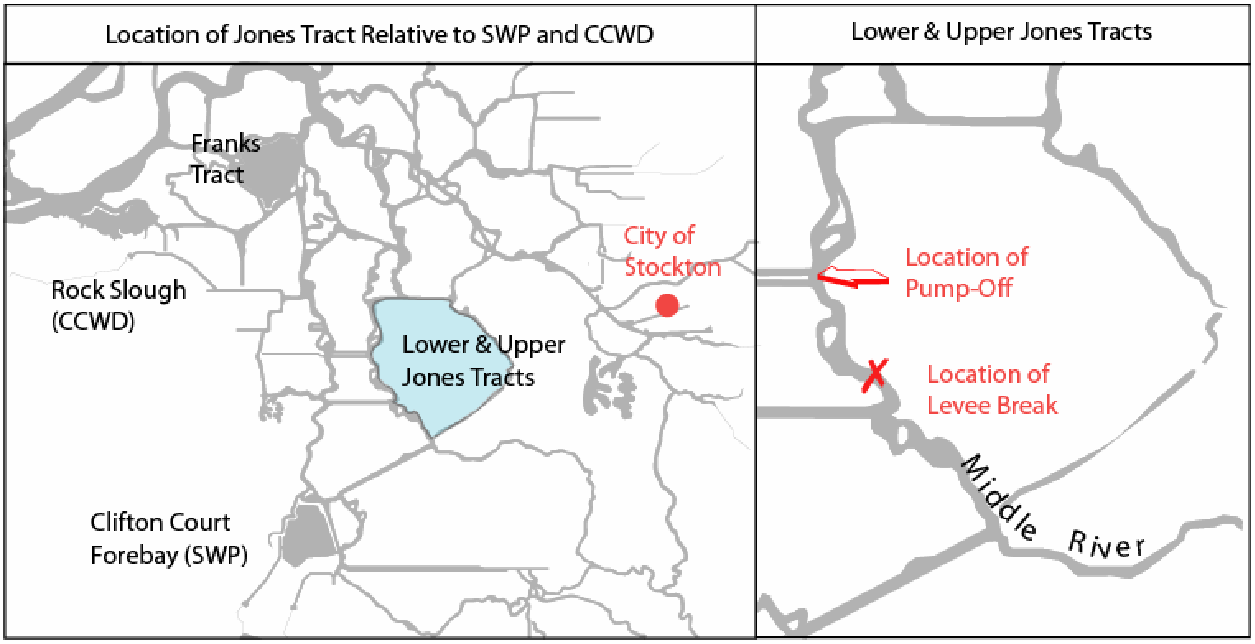

Figure 3.2: Location of Lower and Upper Jones Tracts.

Immediately following the Upper Jones Tract levee break, DWR's Division of Operations and Maintenance (O&M) needed to incorporate the flooded Upper and Lower Jones Tracts into its regular short-term forecasts. Because these forecasts were after the break, O&M hydrodynamic and EC forecasts assumed that the two islands were already flooded and allowed water to move in and out of a combined Jones Tract reservoir (see Figure 3.2) based on differences in the stage inside the island reservoir and the Middle River.[1] When the levee breach was assumed closed, the island was no longer directly simulated in DSM2. Instead releases from the island were simulated as a new boundary input into the Delta. The flows associated with these operations were estimated based on information provided by field crews.

Because the long-term forecasts and historical update also focused on organic carbon impacts due to both the flooding and pump-off associated with Jones Tract, a more detailed representation of the two islands was developed for DSM2. The representation of Jones Tract

[1] Immediately after the break, O&M ran DSM2 historical simulations that included estimates for the flows onto the islands in order to develop initial conditions for the short-term forecasts, but as the forecast period moved further away from the levee failure event, the need to estimate this dynamic response was unnecessary in the short-term forecasts.

used in the long-term forecasts and historical simulation is described below in three sections: the treatment of Jones Tract as a flooded island, the levee break and repair, and the pump-off operations.

3.4.1 Jones Tract as a Flooded Island

Although Upper and Lower Jones Tracts are divided by the Santa Fe Railroad, an access road that runs under the railroad tracks connects the two islands and allowed water to travel from Upper Jones Tract to Lower Jones Tract and flood both islands. Because flooded islands are treated as well-mixed reservoirs in DSM2, there was not enough information available to justify simulating Lower Jones Tract as a separate island reservoir. Instead, a single reservoir was used to represent both Upper and Lower Jones Tracts. The reservoir was opened at the time of the break as described below in *Section 3.4.2*.

```
# Boundary flow input file
# DSM2 Real-Time Simulations
# Updated: 2005.02.27 mmierzwa

# JONES TRACT GEOMETRY
#
# Reservoir Grid Map Info:
# 6. Jones Tract (JONES) <-- Levee Break 2004.06.03

# NOTE: Place this file *before* the original reservoirs.inp in the dsm2.inp file
# Due to a programming style you have to name jones tract as "baconisland"

RESERVOIRS
NAME         AREA   STAGE  BOTELV NODE   COEFF2RES    COEFF2CHAN
baconisland  522.72  -13.9 -14.0  118    2000.        2000.
END

# Source: Correspondence with Rob DuVall and field trips from Oct - Dec, 2004
# Jones Tract Assumptions:
# - Ave. Depth = -5 m NGVD --> ~ -15 ft NGVD (MWQI)
# - Surface Area = 12,000 acre = 523 E06 sq. ft
# - Calculated Storage Capacity @ 0 ft NVGD = 180 TAF
# - Single Breach near Woodward Isl.
# - Coeff in / out based on calibration of model / USGS 15-min data in mid and old r
```

Figure 3.3: Example Jones Tract Configuration in a DSM2 Input File.

An example of the DSM2 input code that was used to represent the combined Jones Tracts is shown in Figure 3.3. The organic carbon growth algorithm was originally developed as part of the In-Delta Storage program. Because of the way the DSM2-QUAL organic carbon growth algorithm was programmed and the need to quickly forecast the water quality impacts of the Jones Tract event, the Jones Tract island reservoir was named “baconisland.” The surface area and starting elevation of the reservoir were based on field information provided by a number of DWR and US Geological Survey sources. Because these sources estimated slightly different values for the surface area and island land surface elevations, these numbers were refined during the DSM2 calibration. Furthermore, the “COEFF2RES” and “COEFF2CHAN” variables were determined after running a series of simulations using different coefficients to regulate the amount of flow into and out of the reservoir and comparing DSM2 stage and flow results in the south and central Delta with field results.

Based on a bookend approach that was originally developed in support of In-Delta Storage planning studies (Mierzwa and Pandey, 2003), two different organic carbon growth rates were used to simulate increases in organic carbon concentrations due to flooding an island rich in peat soils. The organic carbon growth rates varied each month, as shown in Table 3.2. The results of both the high and low bookends were compared with organic carbon Jones Tract grab samples from Municipal Water Quality Investigations (MWQI) and the measured organic carbon at SWP's Clifton Court Forebay (see *Section 3.7.2*).

Table 3.2: DSM2 Jones Tract Organic Carbon Growth Rates ($gC/m^2/day$).

Growth Rate	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
High	0.50	0.00	0.00	0.00	0.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Low	0.05	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05

3.4.2 Jones Tract Levee Break and Repair

The Jones Tract levee break and repair were simulated in DSM2 by treating the levee break as a gated structure. When the reservoir gate was opened on June 3 in DSM2, it took three to five days for the island to completely flood. The gate was closed until the time of the levee break, and then closed again when the levee was effectively repaired on June 30. The gate / levee breach was simulated on Middle River near the actual breach location. An example of the DSM2 input code used to control the levee breach is shown in Figure 3.4. The jones.dss file shown in Figure 3.4 contains the opening and closing times of the reservoir gate.

```
GATES
NAME           OPER    NODE
baconisland    time    118
END

# gate timing from other dss files
INPUTPATHS
NAME        A_PART     B_PART         C_PART  E_PART     F_PART   FILLIN  PRIORITY  FILENAME
Baconisland hist+gate  ${JONESBREACH} POS     IR-DECADE  DWR-DMS last    0 ./timeseries/jones.dss
END
```

Figure 3.4: Example Jones Tract Levee Breach in a DSM2 Input File.

In order to prevent a numerical instability that would cause the model to abort when the levee was opened, DSM2-HYDRO's computational time step was shortened from the normal 15 minutes to 5 minutes. This time step was used in all of the scenarios. These scenarios were designed to test the sensitivity of DSM2 flows and stage to different levee break times, effective levee repair dates, pump-off flow rates, and organic carbon growth rates.

Even when using a 5-minute computational time step, changing the time of the levee break would result in small differences in the flow into and stage inside of Jones Tract for the week following the break. The timing of the closure of the levee breach was significant in determining the maximum water level inside the DSM2 island reservoir. For example, if the levee breach was closed near a low tide, the water level (and hence volume of water stored on the islands) would be lower than if the levee breach was effectively closed near a high tide. In reality, as the levee breach repair neared completion, changes in Middle River water levels would have a less significant impact on the amount of water exchanged between the flooded islands and the Delta. However, given the lack of detailed information regarding the amount of water that was stored on Upper and Lower Jones Tracts when the breach was closed, it was not possible to time the DSM2 closure of the levee breach to match a target storage volume.

3.4.3 Jones Tract Pump-Off

Because the flow rate of water pumped off the two islands was not directly measured, it was necessary to estimate this flow in order to correctly simulate the historical hydrodynamic and water quality impacts the draining of Jones Tract had on the Delta. Water was removed from both islands via a series of pumps and pipes, which had a combined maximum capacity of 800 cubic feet per second (cfs). It was assumed that the actual pump-off flow rate was near this value from mid-July through mid-September. In mid-September the pumps on Upper Jones Tract were shut down, leaving only the Lower Jones Tract pumps operational. Located on either side of the Santa Fe Railroad, both sets of pipes discharged Jones Tract water to the Middle River near Santa Fe Cut and the southern end of Bacon Island.

By using the dates when (1) pumping began, (2) the Upper Jones Tract pumps were shut down, and (3) the Lower Jones Tract pumps were shut down and by estimating the total volume of water stored on Jones Tract (approximately 180 taf), it was possible to reconstruct the daily average flow rate for the pump-off operations. Figure 3.5 shows the flow rate used in DSM2 to simulate the combined pump-off of both Upper and Lower Jones Tracts. Water was pumped from Jones Tract using an object-to-object approach (Figure 3.6). This approach allowed the organic carbon-rich water from Jones Tract to mix into the Middle River.

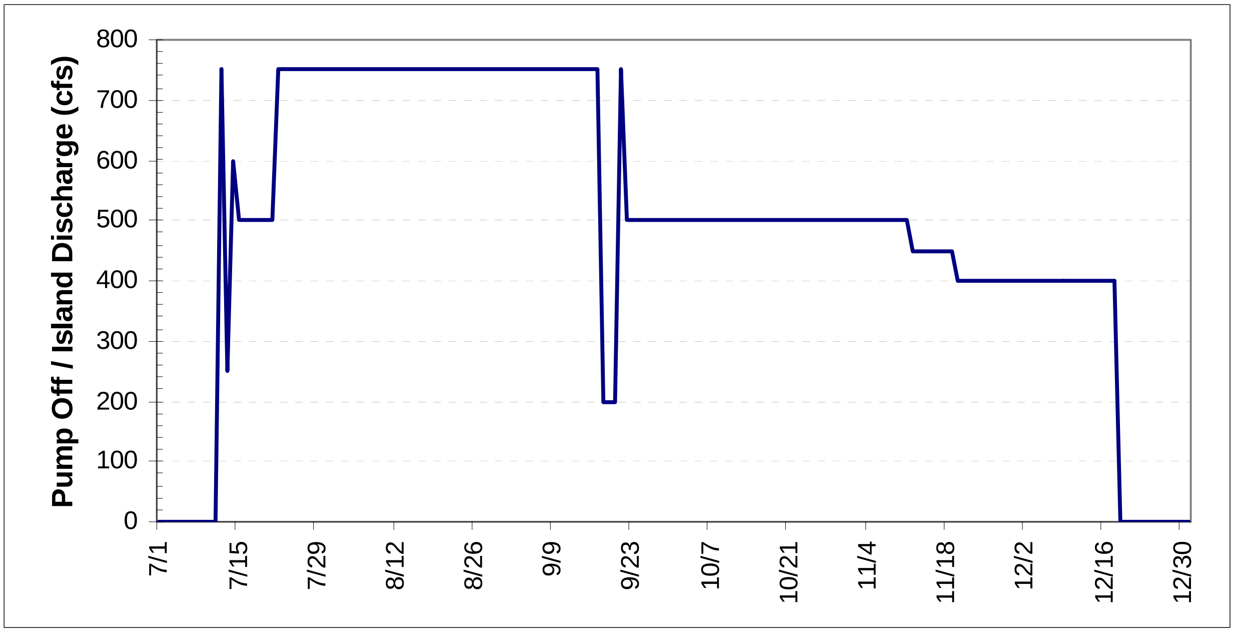

Figure 3.5: Estimated Jones Tract Pump-Off Flow Rate Used in DSM2 Simulation of Historical 2004 Conditions.

```
# JONES TRACT OPERATIONS
# To move water to / from the ISI-IDS project islands
OBJ2OBJ
FROM_TYPE      FROM_NAME      TO_TYPE        TO_NAME        INPUT_LABEL
reservoir      baconisland    node           121            jonespump
END

# Jones Tract Levee Breach Scheduled Releases
# jonespump for object-2-object
INPUTPATHS
name           a_part         b_part  c_part  e_part  f_part         fillin  filename
jonespump      hist+chan      jones   flow    1DAY    ${PUMPOUT}     last    ./timeseries/jones.dss
END

TYPE
STRING         PART   MATCH   ACCOUNT
/JONES/FLOW    P      sub     RIM
END
```

Figure 3.6: Example of Jones Tract Pump-Off in a DSM2 Input File.

3.5 DSM2 Scenarios

More than 38 different scenarios were run in order to test the sensitivity of the DSM2 parameters and assumptions described above. In this report, the historical simulation is presented in the hydrodynamics section, and results of two organic carbon growth rate scenarios and two alternative scenarios are presented in the water quality section. A summary of the scenarios presented in this report is shown in Table 3.3.

Table 3.3: Summary of DSM2 Jones Tract Scenarios.

Scenario	Date of Levee Break	Date of Pump-off	Organic Carbon Growth Rate
Historical (High Growth)	Jun 3	Jul 12	0.50 $gC/m^2/day$
Historical (Low Growth)	Jun 3	Jul 12	0.05 $gC/m^2/day$
No Pump-off	Jun 3	-	0.50 $gC/m^2/day$
No Break	-	-	0.50 $gC/m^2/day$

The two different organic carbon growth rate scenarios were chosen in order to provide bookends for likely organic carbon concentrations in Jones Tract. The monthly varying organic carbon growth rates used in these two scenarios are shown in Table 3.2 (see *Section 3.4.1*). The historical hydrodynamic simulation was used for both of these two organic carbon simulations, thus the only difference in water quality between these two scenarios was due to the organic carbon growth rates.

The two alternative scenarios were conducted to determine the impact of the Jones Tract levee breach and the pump-off operations. The impact can be accessed by comparing the two organic carbon growth rate, historical flow-based simulations with observed water quality data with the model results from the two scenarios.

3.6 Hydrodynamic Modeling

The calibrated Jones Tract DSM2 simulation was incorporated into the annual DSM2 2004 South Delta Historical Hydrodynamic simulation. Suits et al. (2005) provides a more detailed description of the boundary conditions and model results of the 2004 historical simulation. This report compared the DSM2-simulated stages and flows at several locations in the south Delta. Below is an overview of hydrodynamic information presented in this report.

3.6.1 Geometry

The changes incorporated into DSM2 to represent Upper and Lower Jones Tracts are described in *Section 3.4*. All three south Delta temporary agricultural barriers and the spring and fall fish protection barriers at the head of Old River were installed in 2004. Timing of the installation and removal of all four structures was estimated based on 15-minute observed water level data. The Delta Cross Channel and Clifton Court Forebay gates were operated according to their historical schedules. The Delta Cross Channel was opened on June 3, 2005, shortly after the levee break.

3.6.2 Hydrology

The flow and stage values used as boundary conditions in DSM2 were downloaded from the Interagency Ecological Program (IEP) and California Data Exchange Center (CDEC) web sites. The daily average flows for the major DSM2 flow inputs—Sacramento River, Yolo Bypass, and San Joaquin River—are shown in Figures 3.7, 3.8, and 3.9. Although 2004 was classified as a Below Normal water year, flows were high on each of the three main Delta tributaries in late February through March 2004. However, in the month preceding the Jones Tract levee break, Sacramento River and Yolo Bypass flows were fairly low. The increases in San Joaquin River flows in mid-April through mid-May were part of VAMP and correspond with a 31-day decrease in SWP and CVP exports.

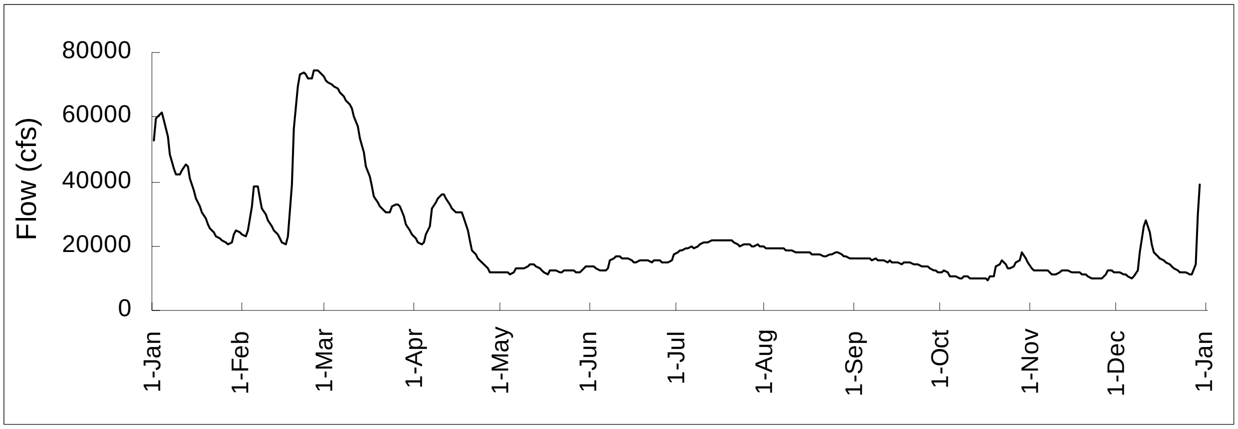

Figure 3.7: Sacramento River 2004 Daily Average Historical Flows.
(Source: Suits et al., 2005)

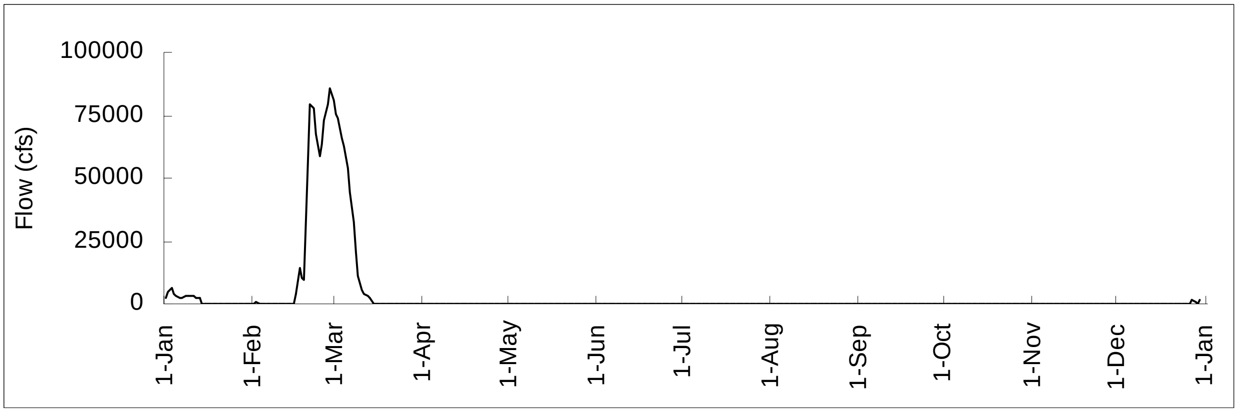

Figure 3.8: Yolo Bypass 2004 Daily Average Historical Flows.
(Source: Suits et al., 2005)

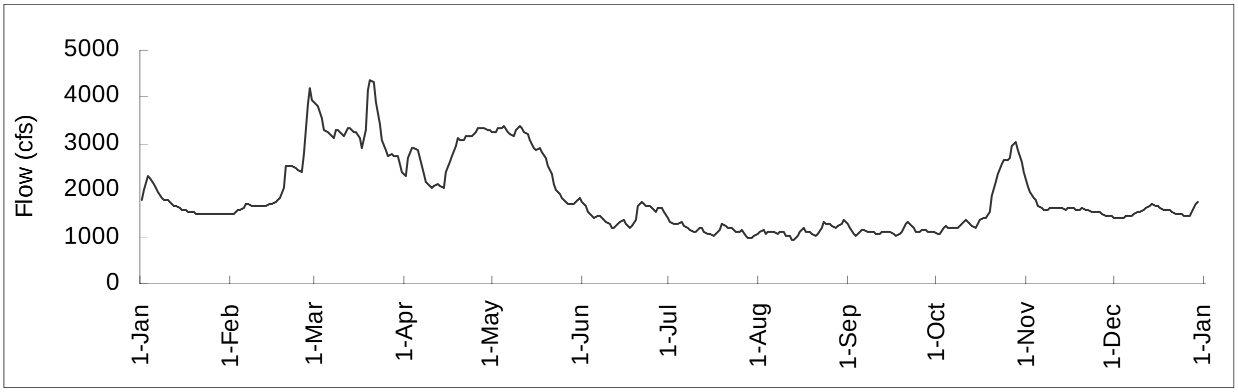

Figure 3.9: San Joaquin River 2004 Daily Average Historical Flows.
(Source: Suits et al., 2005)

Historical consumptive use in the Delta was estimated by the Delta Island Consumptive Use (DICU) model, which uses precipitation, pan evaporation, and water year type to determine the agricultural water needs in the Delta and distribute these flows throughout the DSM2 model domain. The agricultural demands for Upper and Lower Jones Tract were not altered, even though the flooding of the islands eliminated agricultural use. However, during the pump-off operations, the existing agricultural drains and return siphons were used to assist removing water from the flooded island.

3.6.3 Hydrodynamic Results

The hydrodynamic results are presented according to stages in the south Delta, flows in the south Delta, and flows and water levels inside Jones Tract. The stages and flows presented in this report for the south Delta were taken from Suits et al. (2005). A more detailed description of the 2004 simulated hydrodynamics for the south Delta can be found in that memo. A few locations that are near the Jones Tract levee break and pump-off locations are also presented here.

Stages in the South Delta

Suits et al. (2005) showed that the DSM2-simulated stages generally followed the observed daily maximum and minimum stage at several locations in the south Delta. Stage results for 2004 for two locations near the Jones Tract levee break, Old River at Rock Slough (ROLD024) and Middle River near Tracy Blvd. (RMID027), are shown in Figure 3.10. DSM2 consistently modeled the minimum stages in the Old River at Bacon Island about one foot below field observations. Suits et al. (2005) showed several other locations with similar trends, but it is important to note that this trend was not limited to the period when Jones Tract was flooded.

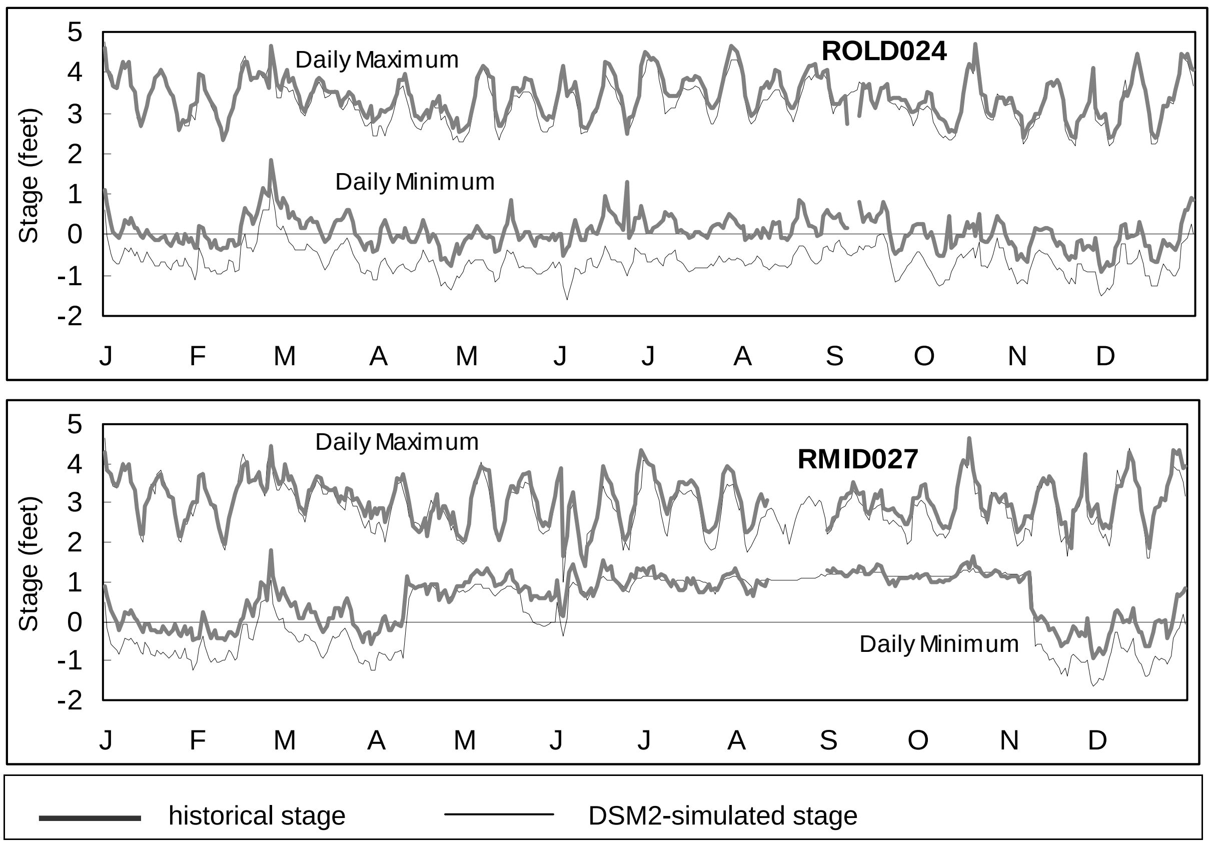

Figure 3.10: DSM2 and Observed Old River at Rock Slough and Middle River near Tracy Blvd. Daily Maximum and Minimum Stage.
(Source: Suits et al., 2005)

Flows in the South Delta

Suits et al. (2005) showed the historical and DSM2-simulated daily average flows at several locations in the Delta, including near the Delta Cross Channel and through Three Mile Slough. Daily average flows for Old River near the Contra Costa Water District Los Vaqueros intake (ROLD034) and Middle River at Santa Fe Cut (RMID015) are shown in Figure 3.11. Negative flows represent flows toward the SWP and CVP exports (south). The DSM2-simulated Middle River flows match the historical field data well, including during the period when the Jones Tract was flooded on June 3. DSM2 overestimated Old River flows heading downstream during the levee breach, but shortly after the breach the DSM2-simulated flows matched the historical field data.

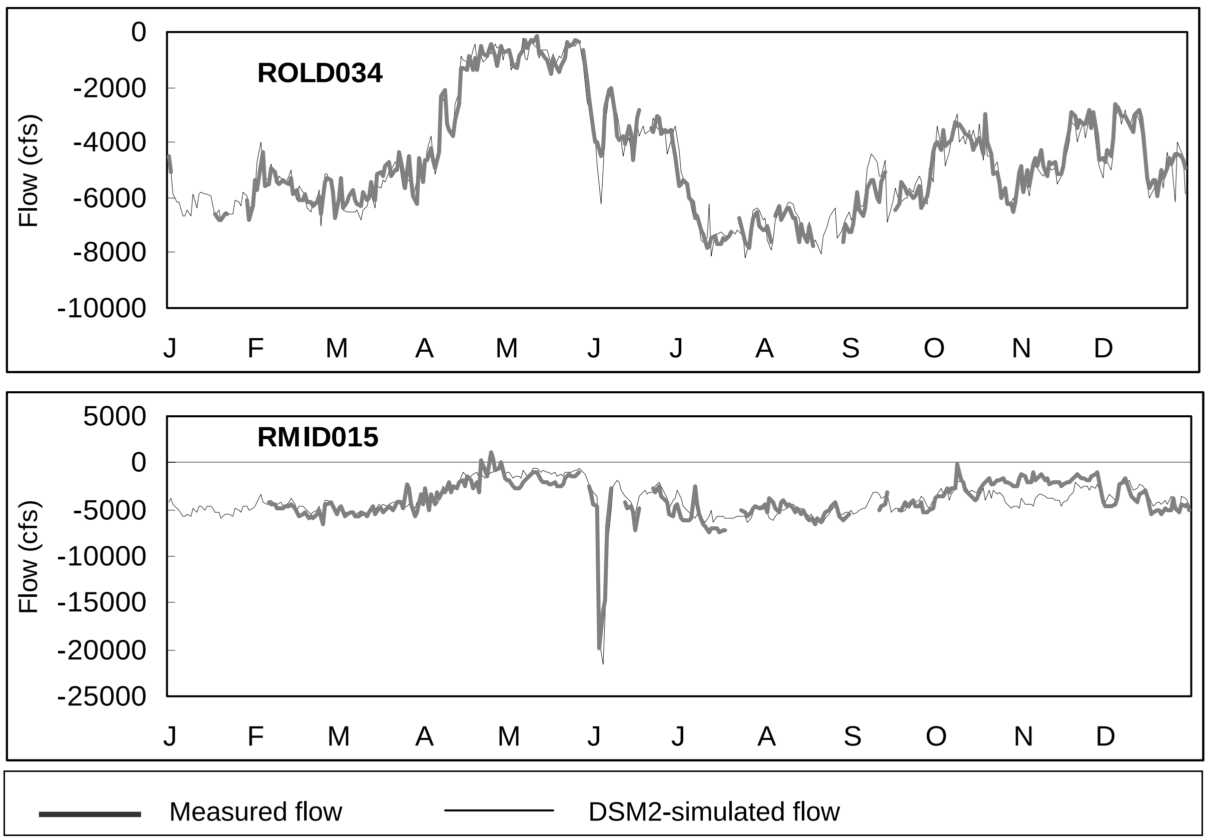

Figure 3.11: DSM2 and Observed Old River at the Los Vaqueros Reservoir Intake and Middle River at Santa Fe Cut Daily Average Flows.
(Source: Suits et al., 2005)

Flow and Stage in Jones Tract

As discussed above, following the failure of the Upper Jones Tract levee, the DSM2 simulation took several days to fill Jones Tract. The island was considered to be filled when the daily average flow in and out of Jones Tract approached zero. As the water levels in the Delta increased and decreased with the Spring / Neap tide cycle, the water levels in Jones Tract also changed. The DSM2-simulated stage in Jones Tract varied between 1 and 2 feet (NGVD) during June. The stage outside of Jones Tract on the Middle River near Santa Fe Cut varied between minus-1 foot and 4 feet during this same period, suggesting that the levee breach was dampening a significant amount of the tidal variation in the model. Unfortunately, no accurate measurements of stage inside or flow in and out of either Jones Tract island could be used to validate these DSM2 results.

Figures 3.12 and 3.13 show the simulated water levels inside and flows into Jones Tract during the first several days after the levee failed. The shaded period in Figure 3.12 represents a transition period when the islands began to show some tidal effect on water level, but over the course of a tidal cycle more water was still entering the islands than leaving. The DSM2-simulated flow in and out of Jones Tract for the rest of June is shown in Figure 3.14. The DSM2-simulated stage inside Jones Tract and on Middle River near Santa Fe Cut for the rest of June is shown in Figure 3.15. The gradual change in minimum and maximum stage for both locations was related to the Spring / Neap tide cycle.

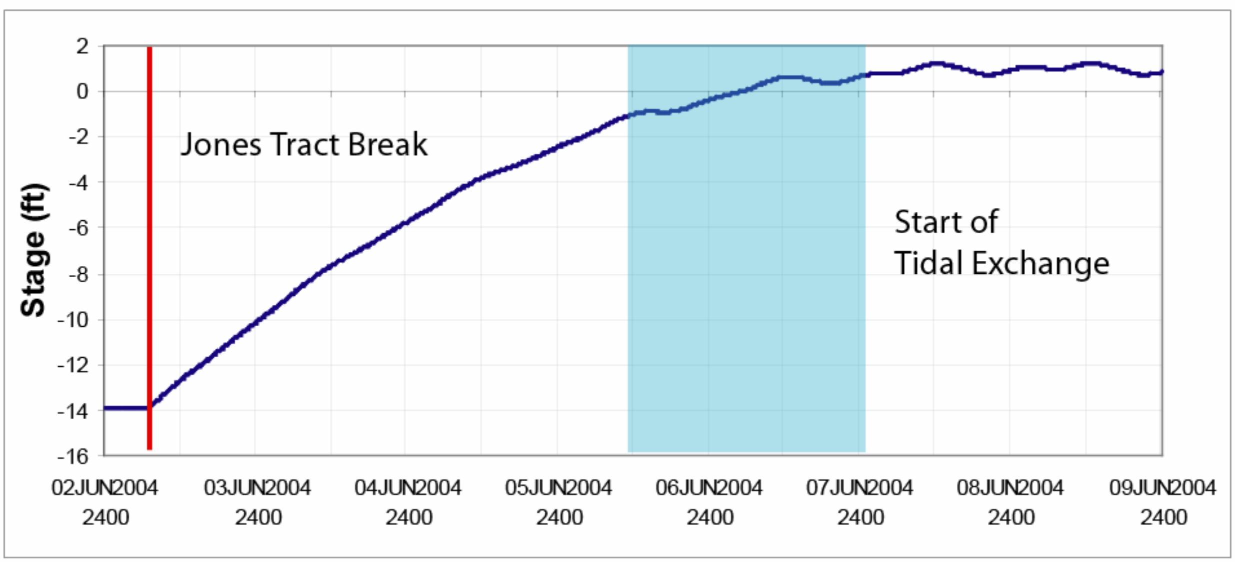

Figure 3.12: DSM2 Stage inside Jones Tract While Jones Tract Filled.

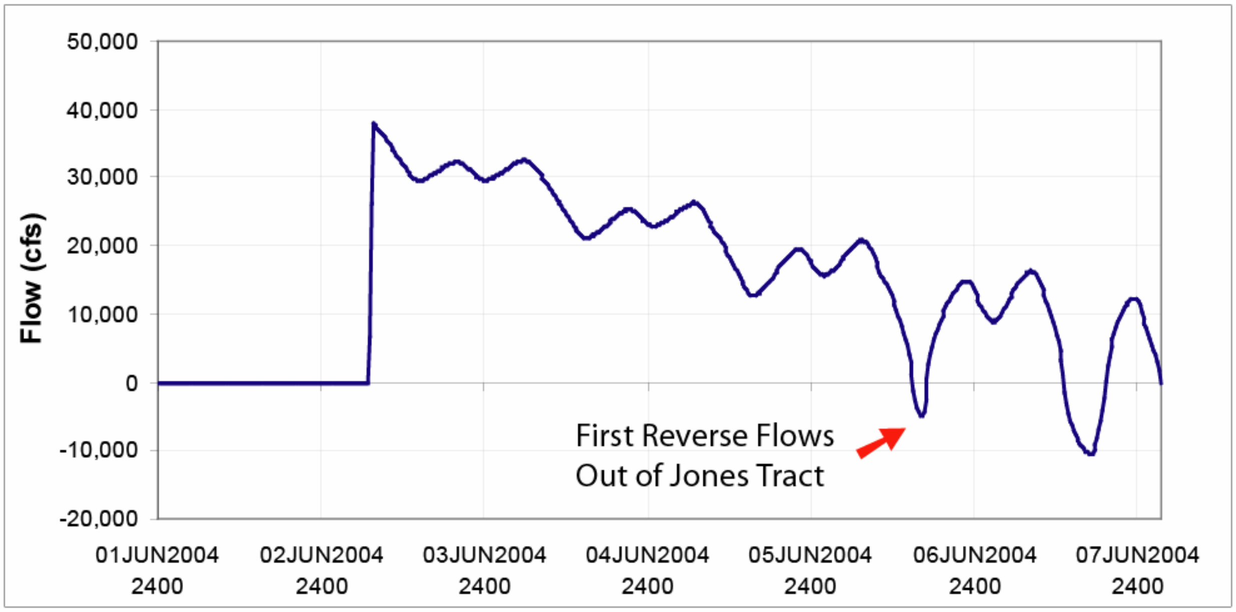

Figure 3.13: DSM2 Flows In (Positive) and Out (Negative) of Jones Tract While Jones Tract Filled.

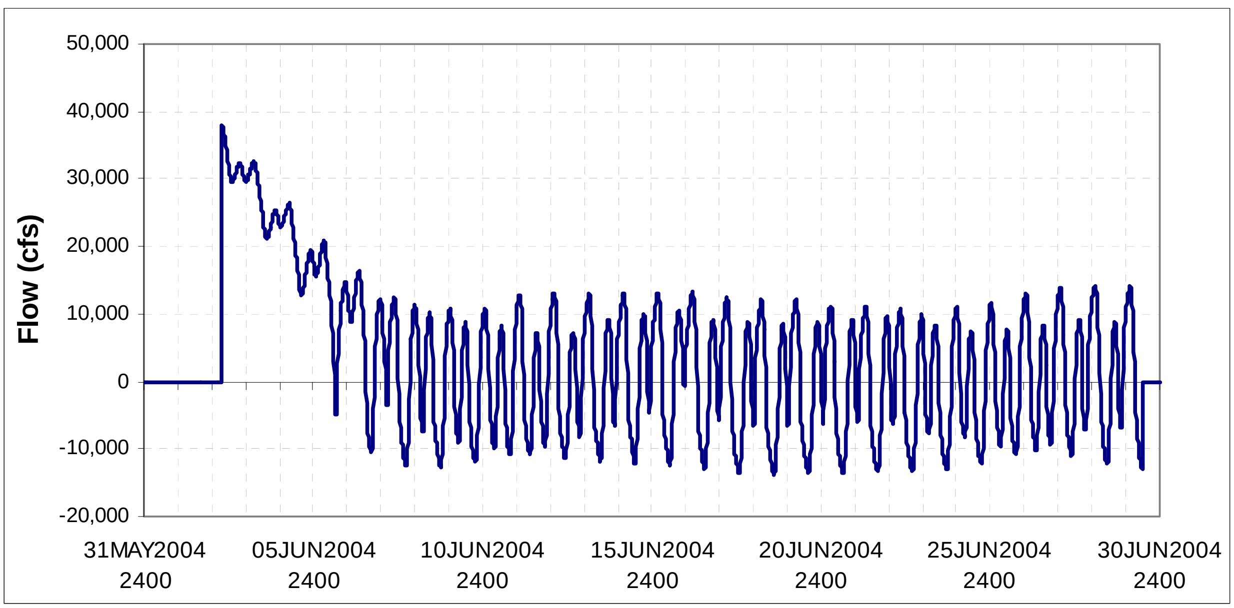

Figure 3.14: DSM2 Flows In and Out of Jones Tract in June 2004.

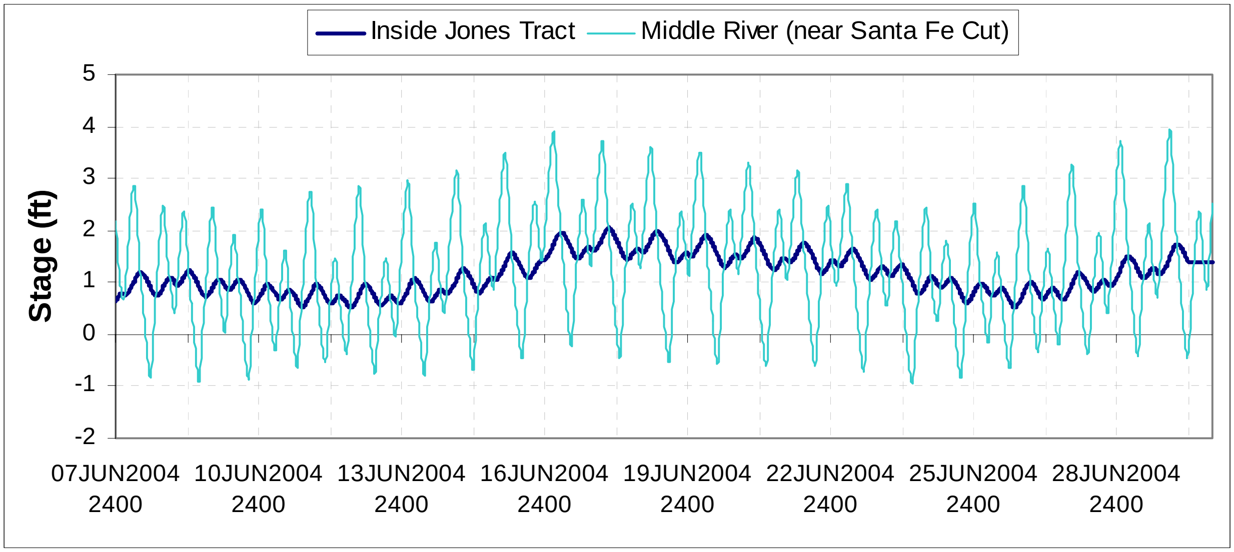

Figure 3.15: DSM2 15-minute Stage inside Jones Tract and on the Middle River near Santa Fe Cut in June 2004.

3.7 Water Quality Modeling

Simulated EC is a function of both the concentration of EC at the DSM2 boundary conditions and the mixing of the various water sources in the Delta, thus there was need for only one historical water quality simulation for EC. The results of this EC simulation were compared to observed EC at three Delta in-channel locations (Jersey Point, Old River at the entrance to Rock Slough, and Victoria Canal), on Jones Tract, and at SWP's Clifton Court Forebay. Two DSM2 historical flow-based dissolved organic carbon (DOC) scenarios, using high and low DOC growth rates, were run and compared to MWQI grab sample data from Jones Tract and Clifton Court Forebay. Two alternative scenarios were also run for both EC and DOC. These two alternative scenarios were designed to explore the water quality impact of the flooding of Upper and Lower Jones Tracts for the duration of 2004.

3.7.1 Boundary Conditions and Organic Carbon Growth Rates

Daily average DOC time-series at the Delta boundaries were developed using MWQI continuous monitoring data from Freeport and grab sample data from Vernalis and the American River. The daily Freeport DOC was based on a combustion sampling technique and was used as the Sacramento River boundary condition in DSM2. The combustion-based grab sample data from Vernalis were used as the DSM2 San Joaquin River boundary loading condition, but converted to a daily time step by filling in missing daily values using the most recent previous grab sample value. This same procedure was used to develop a daily time step for the loading condition at Mokelumne and Cosumnes rivers (Eastside streams) by using MWQI American River oxidation-based DOC grab samples. Although only data from January 2004 through February 2005 are shown in Figure 3.16, DOC time-series were developed starting in October 2003 in order to remove the impact of assumed initial DOC conditions on the DSM2 simulation of 2004 conditions.

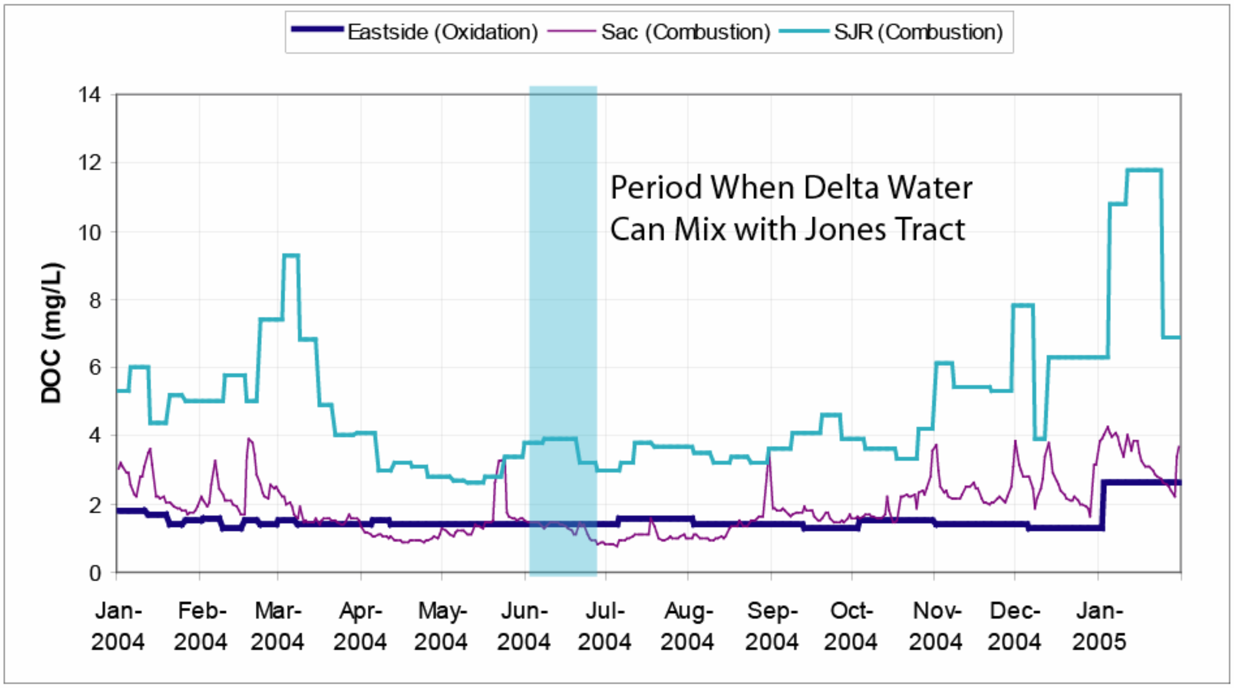

Figure 3.16: DSM2 Dissolved Organic Carbon Boundary Conditions.

The organic carbon growth rates used in the two historical simulations are described in *Section 3.4.1* and Table 3.2. The purpose of the two organic carbon bookend rates was to compare the DSM2 results using both with organic carbon field data and, based on the differences between DSM2 and the field data, determine an appropriate organic carbon growth rate for Jones Tract.

3.7.2 Water Quality Results

The water quality results for all of the scenarios are described in three different sections: various Delta in-channel locations, inside Jones Tract, and inside Clifton Court Forebay. Daily organic carbon samples were only taken at a few locations in the Delta, including Jones Tract and Clifton Court Forebay, which limited DSM2's water quality analysis at various Delta in-channel locations to comparing EC.

EC at Various Delta In-Channel Locations

Because the Delta's in-channel organic carbon field data are limited, only the simulated and observed EC at Jersey Point, Old River at Rock Slough, and along Victoria Canal are presented (Figure 3.17). These three locations can be used to indicate a gradient of salinity from the ocean to the urban exports. In early 2004, both the DSM2-simulated and observed EC at Victoria Canal was slightly higher than the EC at Old River at Rock Slough and Jersey Point. However, in early June (around the time Jones Tract flooded), EC significantly increased at Jersey Point and Old River at Rock Slough. Unfortunately, the observed Old River at Rock Slough EC was not available in most of June 2004. The increase in Jersey Point and Old River EC relative to Victoria Canal EC is typical in the summer and late fall when Sacramento River flows often begin to decrease. However, the timing of this EC increase in Delta can change from year to year.

Prior to the break, the DSM2-simulated daily average EC matched the daily average field data at all three locations. Following the break, the simulated EC still matched the Victoria Canal field observations, but overestimated the Jersey Point EC from June through mid-September and underestimated the Old River at Rock Slough EC from late-September through October.

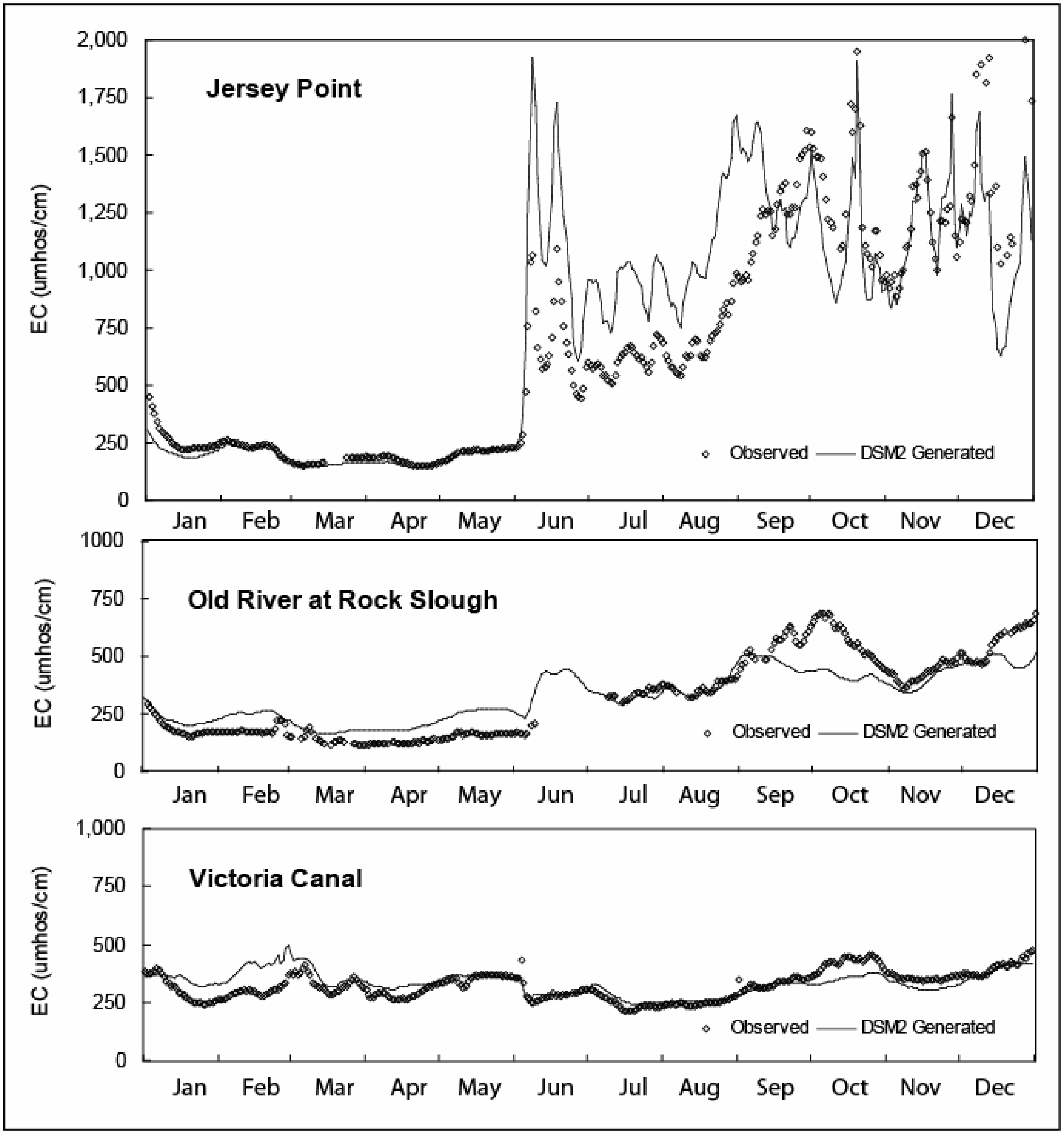

Figure 3.17: DSM2 and Observed Delta In-channel EC in 2004.

A closer view of the Delta's EC response to the flooding and repair of Jones Tract is shown in Figure 3.18, which is divided into four periods: the filling or "transition" period, the tidal exchange period when the islands exchange water with the Middle River based on the tidal cycle, the isolation period starting when the levee was repaired, and the pump-off period when water from the islands was introduced back into the Middle River. During the flooding period, Jersey Point and Old River EC increased, and Victoria Canal EC slightly decreased. Once Jones Tract was filled, both DSM2 and the observed data showed no significant changes in the EC at the three locations.

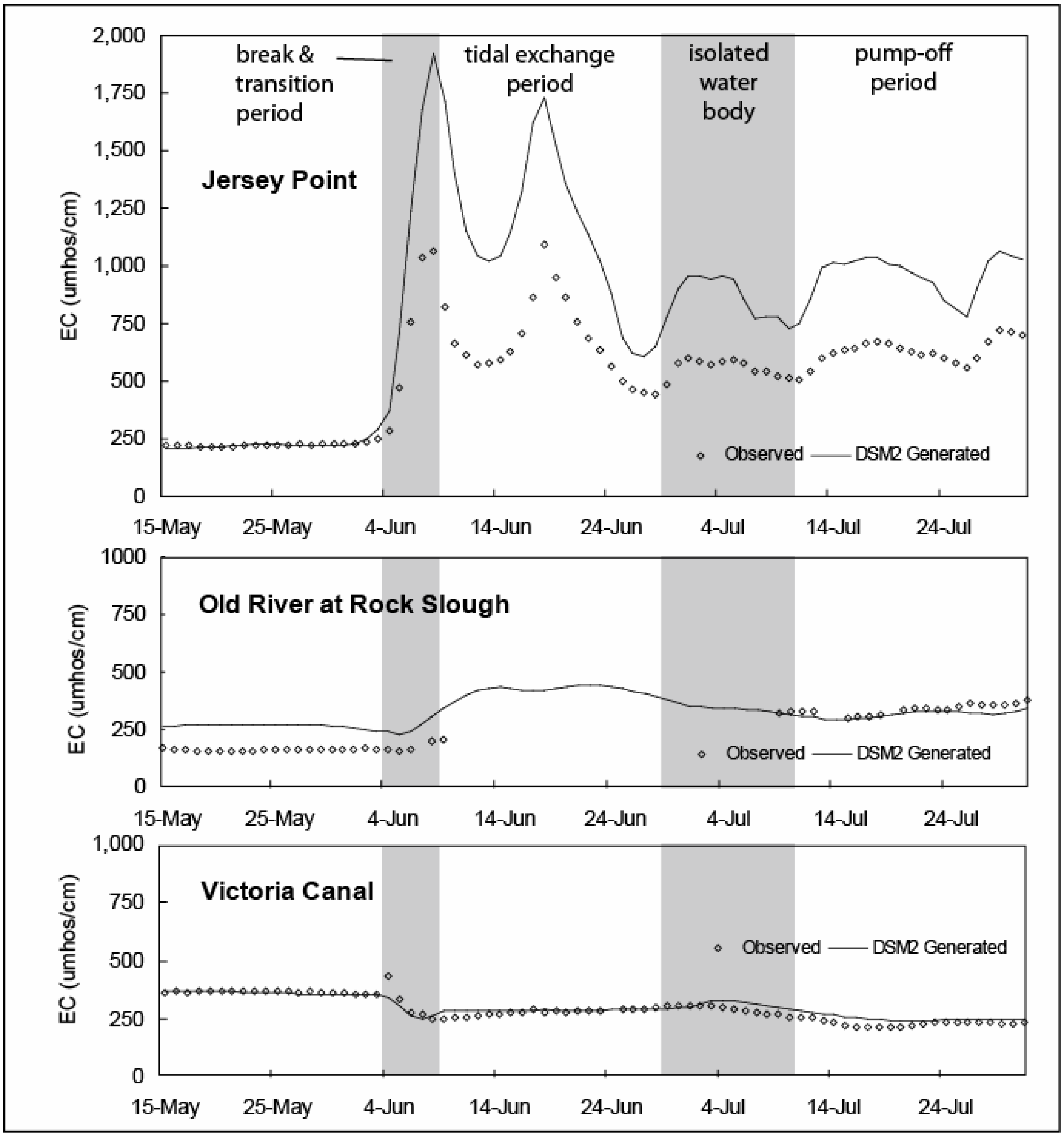

Figure 3.18: DSM2 and Observed Delta In-channel EC during the Jones Tract Flooding and Levee Repair Periods.

EC and DOC in Jones Tract

MWQI collected EC and DOC grab samples at several locations in flooded Upper and Lower Jones Tracts (DuVall et al., 2005). The organic carbon grab samples were measured by both wet oxidation and combustion analytical methods on approximately a weekly basis from early June through late November 2005. These grab samples represent the only organic carbon data collected from a flooded peat soil-rich Delta island, and were used in the analysis of the DSM2-simulated water quality results (Figures 3.19 and 3.20).

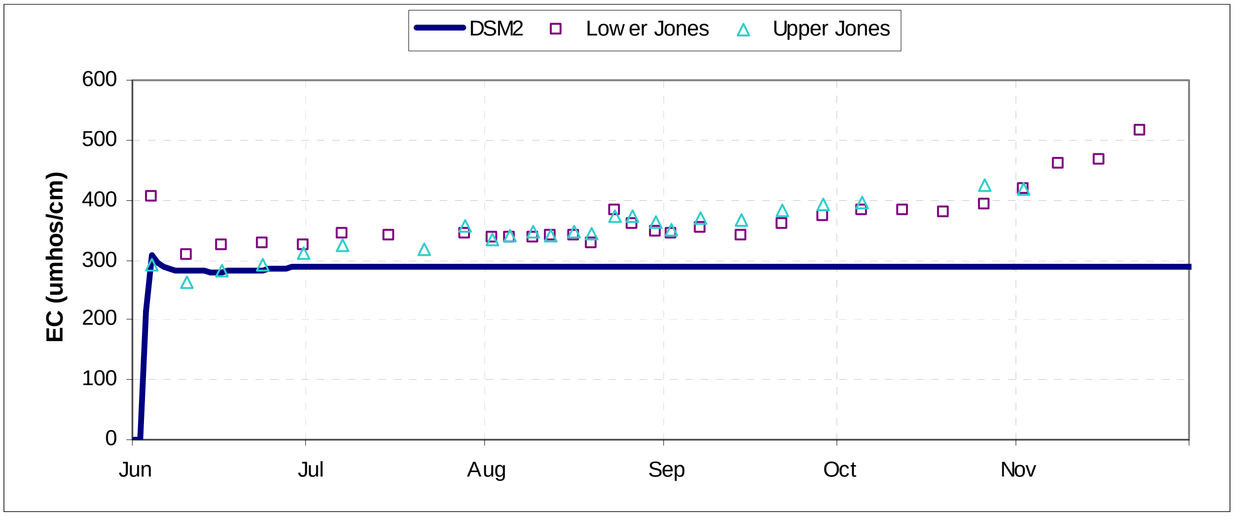

Figure 3.19: DSM2 and Observed Electrical Conductivity in Flooded Jones Tract in 2004.

Once the Jones Tract levee was repaired, the DSM2 EC concentration on the island did not change. However, the MWQI grab samples on both Upper and Lower Jones Tracts indicate that the concentration of EC slowly increased through the beginning of December (the last grab samples were collected in late November). By late November the difference between the simulated and observed Jones Tract EC was around 200 umhos/cm. The volume and depth of water stored on Jones Tract began decreasing on July 12 when the pump-off operations began.

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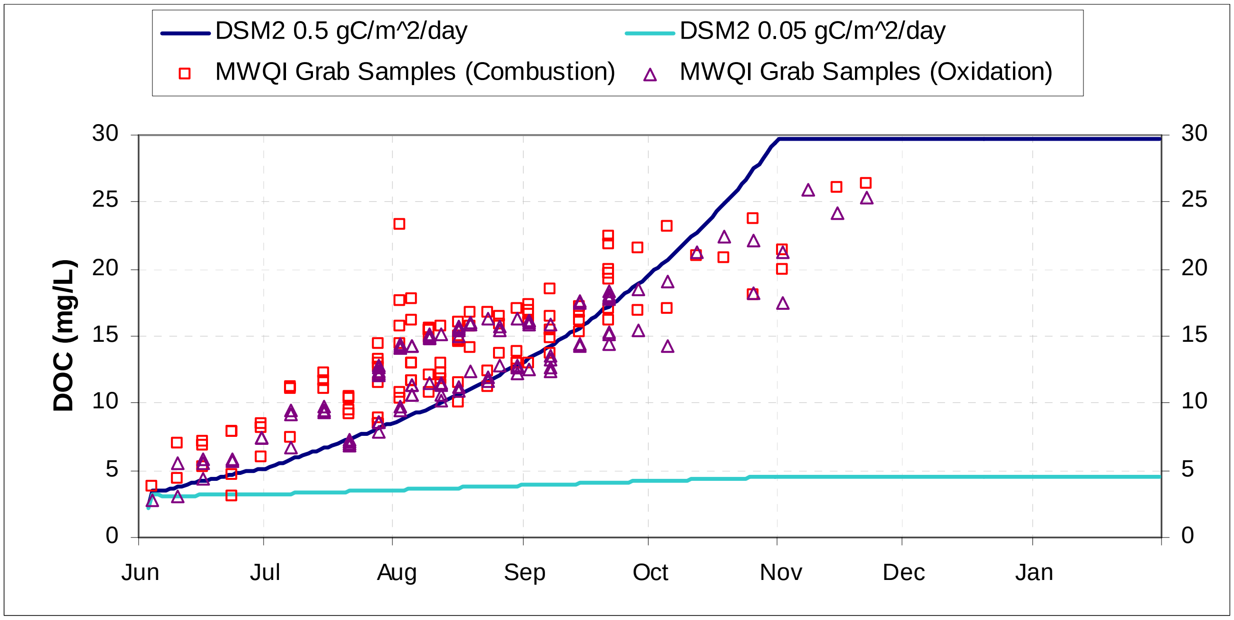

Figure 3.20: DSM2 and Observed Dissolved Organic Carbon in Flooded Jones Tract in 2004.

The DSM2-simulated DOC based on the 0.5 gC/m^2/day (high-bookend) organic carbon growth rate only slightly underestimated the observed DOC in June through September, and slightly overestimated the observed DOC in October and November. Overall the DSM2-simulated DOC based on the high-bookend simulation generally followed the measured DOC values. The 0.05 gC/m^2/day (low-bookend) organic carbon growth rate resulted in no significant increase in the DSM2-simulated flooded Jones Tract DOC concentration.

EC and DOC in Clifton Court Forebay

In addition to the historical simulation, daily average EC and DOC results for the no pump-off and no levee break alternative scenarios for Clifton Court were compared to daily average observed EC and DOC (Figures 3.22 – 3.24). Figures 3.21 and 3.23 illustrate the EC and DOC for all of 2004, while Figures 3.22 and 3.24 focus primarily on the water quality during the Jones Tract flooding and pump-off periods. The no levee break alternative results are only shown for EC (Figures 3.22 and 3.23). With the exception of June 2004, there were no significant differences between the EC and DOC of the no pump-off and non levee break alternatives in Clifton Court.

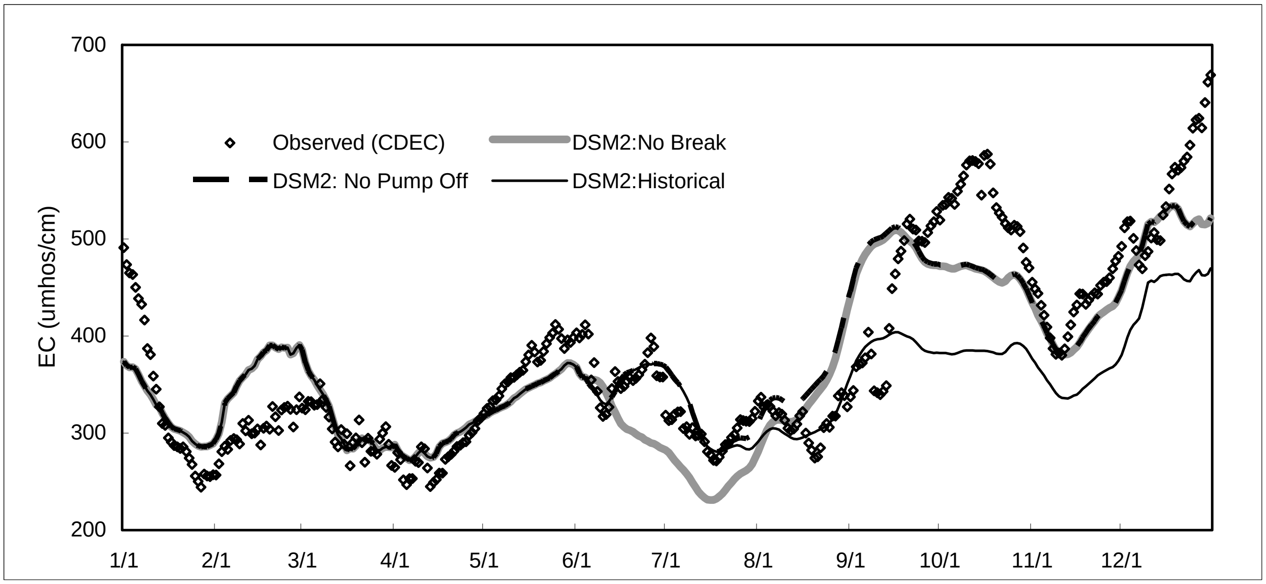

Figure 3.21: DSM2 and Observed Electrical Conductivity at Clifton Court in 2004.

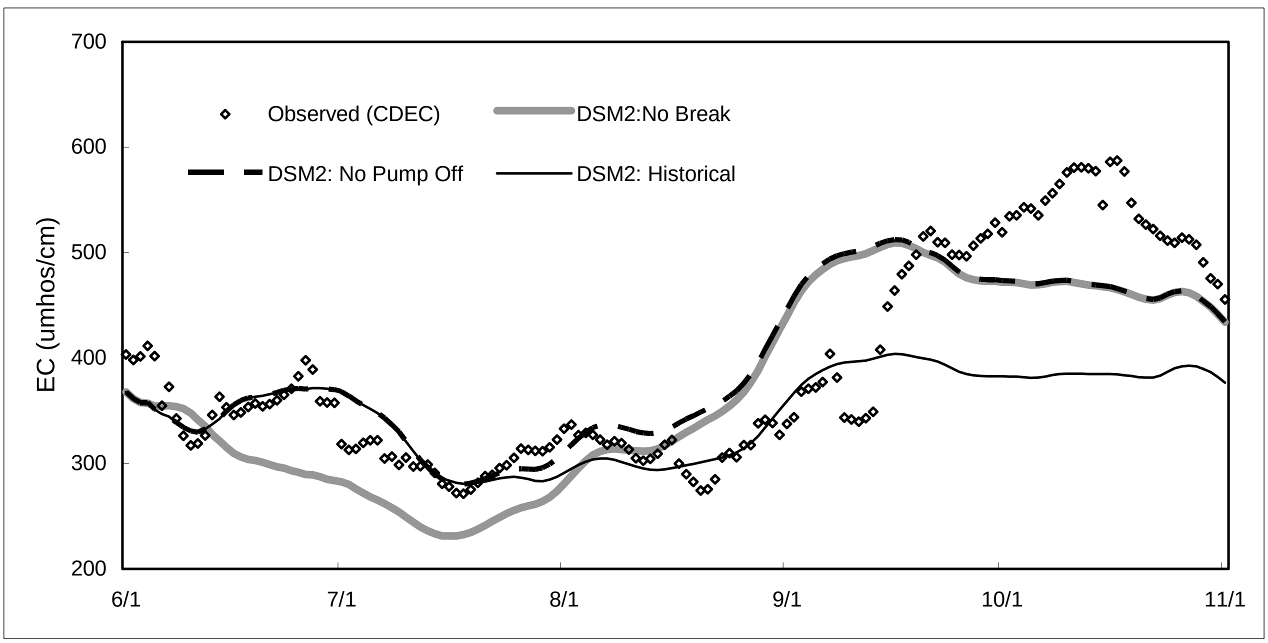

Figure 3.22: DSM2 and Observed Electrical Conductivity at Clifton Court after Jones Tract Flooded in 2004.

The historical DSM2 Clifton Court EC generally followed the observed EC through mid-September 2005, but mid-September through November the simulated EC underestimated the observed EC by a maximum of 200 umhos/cm. Although DSM2 also underestimated the EC on Jones Tract, thus accounting for some of the difference between the simulated and observed EC in Clifton Court, DSM2 also underestimated the EC on the Old River at Rock Slough (see Figure 3.18) for the same period. The difference between simulated and observed Old River and Clifton

Court EC may also be related to differences between the assumed and actual agricultural return flow quality (for example, the DSM2 DICU agricultural return flow EC concentrations may be in error).

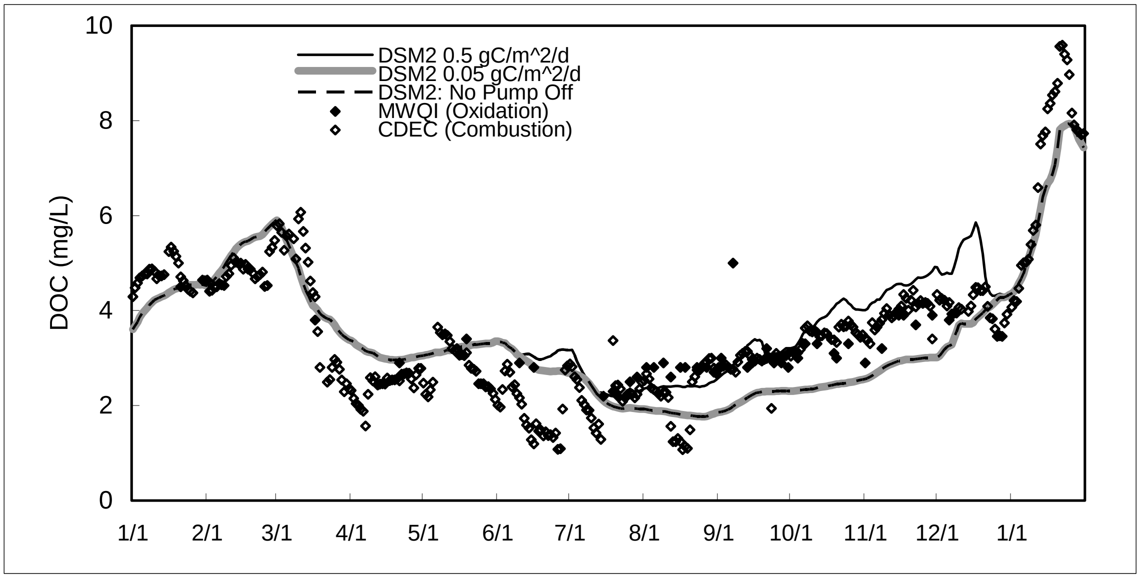

Figure 3.23: DSM2 and Observed Dissolved Organic Carbon at Clifton Court in 2004.

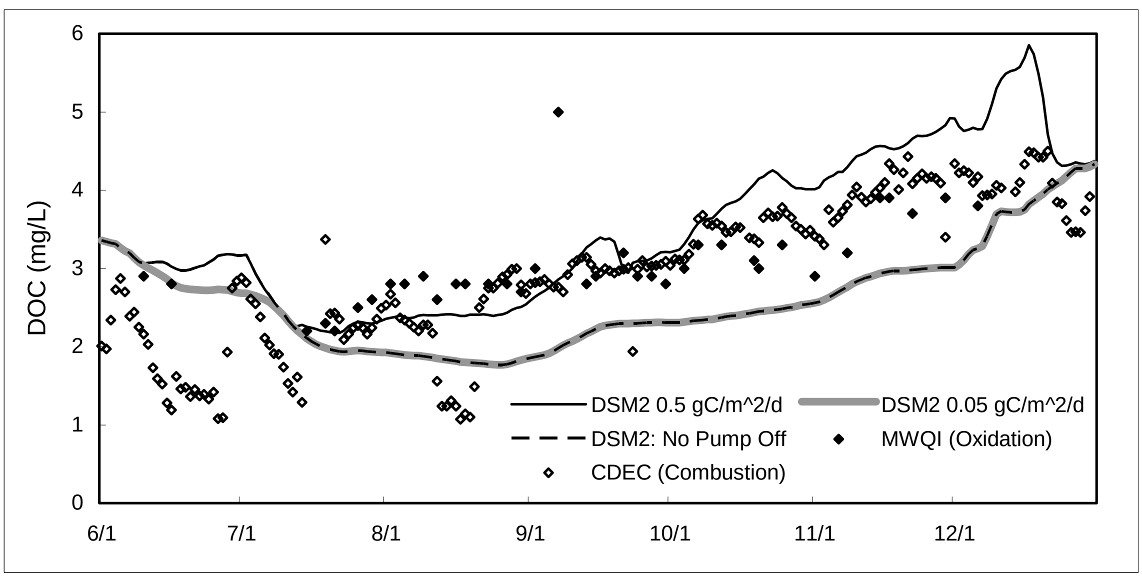

Figure 3.24: DSM2 and Observed Dissolved Organic Carbon at Clifton Court after Jones Tract Flooded in 2004.

The modeled DOC at Clifton Court was compared to both automated daily average combustion-based samples and oxidation-based grab samples (Figures 3.23 and 3.24). The difference was small between the automated combustion and oxidation grab samples in the forebay. With the exception of mid-December, the simulated DOC based on the high DOC growth rate bookend generally followed the observed DOC. In mid-December, DSM2 overestimated Clifton Court DOC by 1 to 2 mg/L for a few weeks. However, by January 2005, DSM2 did a better job at simulating DOC concentrations. By late January 2005, DSM2 was underestimating Clifton Court DOC.

The differences in simulated and observed DOC may be partially explained by limited DOC data from the San Joaquin River, an important source of water to the forebay. The DOC concentrations for the San Joaquin River were based on grab sample data, which were collected less frequently in November 2004 through January 2005. However, as shown in Figure 3.16, the DOC concentrations for the Sacramento River, varied a great deal in January through March 2004 and again in November 2004 through January 2005. If the same daily variability exists on the San Joaquin River, then the over- and underestimation of Clifton Court DOC could be related to under- and overestimations of the organic carbon loading on the San Joaquin River.

From mid-July through mid-December, the simulation using low-growth bookend DOC in flooded Jones Tract consistently underestimated Clifton Court DOC (Figure 3.24). This suggests that the organic carbon concentration of the water stored on Jones Tract increased and that the low bookend growth rate did not account for the amount of additional carbon added to the water on Jones Tract. Not only did both the no break and no pump-off scenarios underestimate Clifton Court DOC, but by mid-July the simulated DOC in both scenarios matched the DSM2 low-growth DOC concentrations. The flooding and pump-off of Jones Tract did result in DOC concentrations in Clifton Court increasing by more than 1.5 mg/L by mid-October.

3.8 Fingerprinting for Jones Tract

In addition to standard EC and DOC simulations, a historical DSM2 volumetric fingerprinting simulation was used to assist in investigating the source of organic carbon and taste and odor drinking water quality problems in Clifton Court. As described by Anderson (2002), volumetric fingerprints can be used to aid in determining the relative contributions of various sources at any given Delta location. In July and August 2004, South Bay Aqueduct users were complaining about taste and odor problems related to SWP water from Clifton Court. In response to these complaints a short July 2004 historical simulation, which included a volumetric fingerprint, was conducted. When the entire 2004 historical simulation was completed in 2005, a new volumetric fingerprinting simulation was conducted (Figure 3.25).

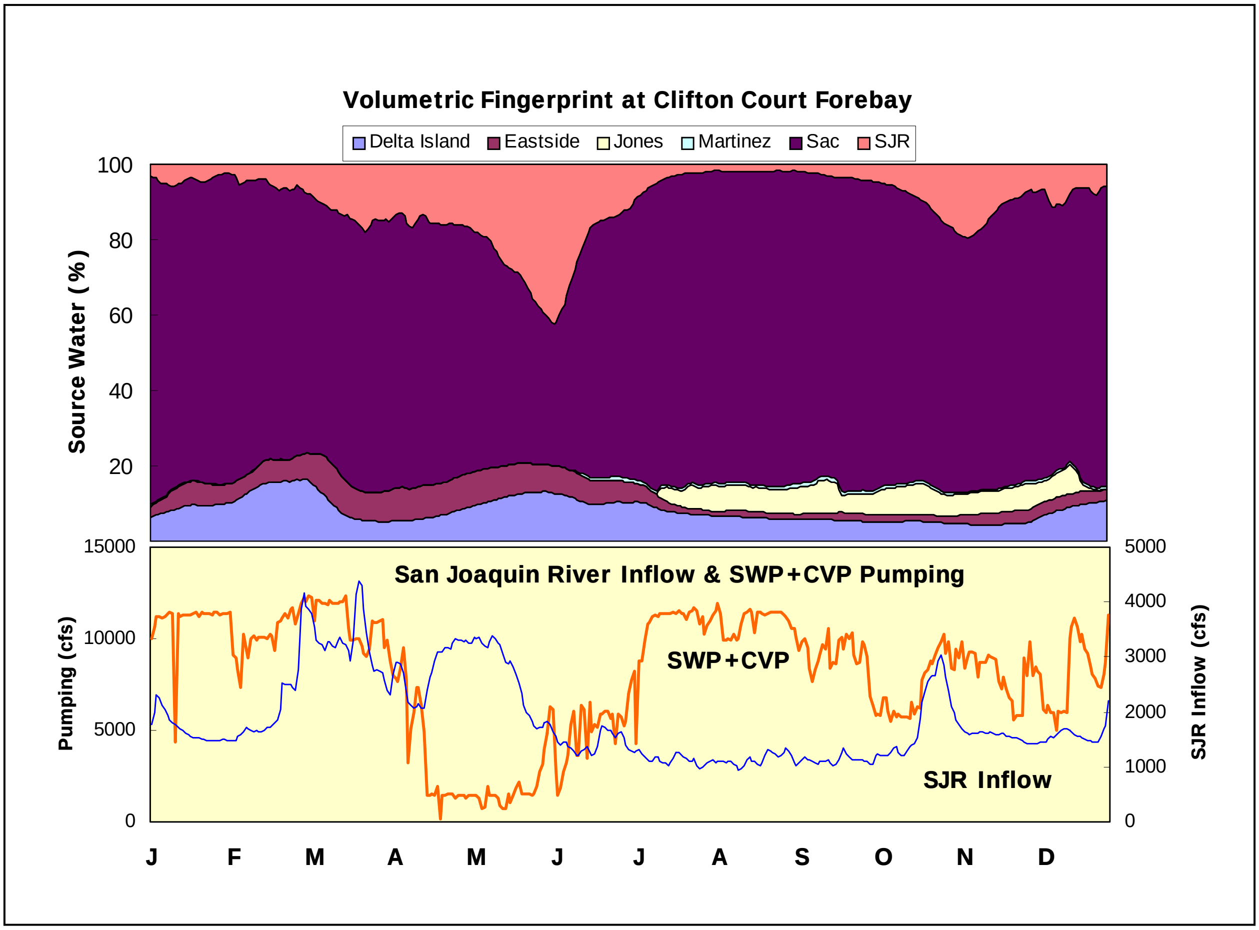

Figure 3.25: Clifton Court 2004 Volumetric Fingerprint.

The results of the historical 2004 volumetric fingerprinting simulation suggest that 5% to 7% of the water reaching Clifton Court from July through mid-December came from Jones Tract. Furthermore, the fingerprinting results also suggest that a significant volume of the water in the forebay prior to the June 3 levee failure came from the San Joaquin River. The graph under the volumetric fingerprint results in Figure 3.25 displays the combined SWP and CVP exports and San Joaquin River flows. The increase in San Joaquin River water in the forebay in May is in part related to the VAMP increase in San Joaquin River flows in April and May, the operation of the south Delta temporary barriers in April and May, and the mid-May increase in SWP and CVP exports.

Using this technique it would be possible to generate a similar volumetric fingerprint for Jones Tract to gain insight into where the water that filled the islands following the levee break originally came from. Better understanding the source of water in Jones Tract or Clifton Court may aid in finding ways to improve the drinking water quality in Delta exports and address issues like those related to the July and August 2004 taste and odor complaints. Fingerprinting not only is useful in analyzing what has already happened, but also can be very important when included in a water quality forecast. The Jones Tract volumetric fingerprints served as a working example of how DSM2 fingerprinting results could be incorporated into water quality management.

3.9 Discussion

The collection of water quality data on Upper and Lower Jones Tract following the break of the Upper Jones Tract levee on June 3 and subsequent flooding of both islands provided a rare opportunity to validate DSM2's ability to simulate hydrodynamics during a levee break and water quality impacts associated with the flooding of an organic carbon-rich Delta island. Although not originally designed to simulate transient events such as a levee failure, DSM2 must be able to simulate hydrodynamics during a flood event in order to allow the model to run for long continuous periods, such as a multi-year event. Extended historical simulations are instrumental in the calibration and validation of both DSM2's hydrodynamic and water quality modules. Furthermore, since DSM2 has been used to simulate the long-term water quality impacts of the proposed In-Delta Storage project islands, which like Jones Tract are composed of organic carbon-rich peat soils, the Jones Tract pump-off operations provided the first opportunity for the DSM2 organic carbon flooded island routine to be validated with actual organic carbon data collected directly from a flooded Delta island.

Upper and Lower Jones Tracts were simulated as a single reservoir in DSM2 because of limited information on the islands' surface elevations and the volume of water that flooded the islands. The levee breach was simulated by adding a gate to the DSM2 reservoir near the location of the break. The gate was opened at the reported time of the levee breach, 6:51 a.m. (Pacific Standard Time) on June 3, 2004 (DWR, 2004). The amount of water that entered Jones Tract caused instabilities in DSM2 when a 15-minute computational time-step was used, thus it was necessary to use a shorter time-step (5 minutes) to simulate the first few days when Jones Tract was filling. With a few exceptions, the DSM2-simulated daily average, maximum, and minimum flow and stage generally followed the observed (CDEC) flow and stage at several locations in the Delta.

Three different EC and four different DOC scenarios were run in order to evaluate DSM2's flooded island organic carbon growth rate algorithm and also to access the water quality impacts of both the Jones Tract flooding and subsequent pump-off. For most of 2004, the simulated daily average EC at Jersey Point, Old River at Rock Slough, and Victoria Canal followed the same trends as the observed EC. These three Delta in-channel locations were chosen based on the availability of observed data and because they can be used to represent a gradient of water quality from the ocean to the urban exports.

DSM2 underestimated the EC on Jones Tract. Once the levee was repaired, DSM2 had no means to accumulate or add additional EC to the water stored on the island. The source of additional salt could be due to evaporation, seepage (for example, water leaving the island, but trapping the salts behind), or a gradual leaching of the salts on the soils. However, there are not enough field data to suggest what mechanism caused this increase in salt on the island. Until the reason for this increase is better understood, DSM2 will maintain a conservative estimate of flooded island EC.

The underestimation of EC on Jones Tract may explain some of the mid-September through late-October DSM2 underestimation of Clifton Court EC; however, the difference in Jones Tract EC continued through the end of November, while the difference in DSM2 and observed Clifton Court EC decreased in late-October. Although the volume of water pumped off Jones Tract was less in October, November, and December, suggesting that the difference in Jones Tract simulated EC from the observed might have been less important, a volumetric fingerprint of Clifton Court source waters showed that the relative amount of Jones Tract water that reached the forebay remained fairly consistent from July through mid-December. However, a plot of the combined SWP and CVP exports and San Joaquin River inflows illustrated that in October 2004 the combined exports decreased. When the exports increased again in mid-October, San Joaquin River inflow exceeded 3,000 cfs. The volumetric fingerprint showed that the relative contribution of Clifton Court water from the San Joaquin River increased over October and November. Bearing this in mind, it is possible that some of the Delta island agricultural return flow volumes and /or EC concentrations (which change on a monthly basis) may have been off in September 2004, but that it took several weeks for the October DICU flows and concentrations or the increased San Joaquin River flows to reduce these high levels.

The DSM2 historical DOC results from the 0.5 $gC/m^2/day$ (high-bookend) organic carbon growth rate scenario followed the MWQI DOC grab samples, suggesting that 0.5 $gC/m^2/day$ is an appropriate organic carbon growth rate for a flooded Jones Tract. Although the flux of organic carbon into Jones Tract was constant over the first five months that water was stored on Jones Tract, DSM2 DOC concentrations showed a non-linear increase in DOC over these months perhaps because the volume of water was constantly decreasing due to the pump-off operations. This non-linear behavior was most apparent between October and November. However, the MWQI DOC grab samples continued to increase as a linear function through November. DuVall et al. (2005) discussed the possible differences in these growth rates, pointing out that the actual DOC flux rate from the soil to the water on Jones Tract may have been a function of water and soil temperatures. Jones Tract water temperatures collected along with the DOC grab samples significantly decreased from September through November (DuVall et al., 2005). DuVall et al. suggested that a more appropriate implementation of the organic carbon modeling would have been to decrease the organic carbon growth rates in September, October, and November.

Two alternative DOC simulations were used to estimate the amount of additional organic carbon present in the forebay due to the flooding and pump-off of Jones Tract. The simulated DOC from these two simulations consistently underestimated the observed Clifton Court DOC, while the high bookend growth rate results produced a good fit to the observed data from July through mid-October. Although some of the DSM2 overestimation of DOC can be attributed to the late-October and November overestimation of DOC in Jones Tract, the accuracy of the San Joaquin River DOC boundary condition may also have been a cause for the difference between modeled and observed DOC. The San Joaquin River DOC grab samples were collected less frequently in the 2004-2005 winter months, but historically this is the time when DOC on a river can change the most. Given the proximity of the San Joaquin River to Clifton Court, an over- or underestimation of the San Joaquin River DOC can lead to significant errors in DSM2 simulation of DOC in the South Delta. However, despite the difference between modeled historical and observed DOC, the high-bookend growth rate results still did a better job at following the observed Clifton Court DOC. Furthermore, when the pumping stopped in mid-December, the historical and alternative scenarios all quickly merged into a single trend, suggesting that the flooded Jones Tract peat soils were in fact a significant source of organic carbon in the Clifton Court Forebay in 2004.

3.10 Future Directions

The results of the DSM2 Jones Tract studies have been integrated into the standard DSM2 historical simulation. Future DSM2 runs that wish to include 2004, need to find some way to account for the flows into and later out of Upper and Lower Jones Tracts. Based on the relatively good fit of stage, flow, and EC data at several Delta in-channel locations and Clifton Court, it is recommended that the procedure used in this simulation be adopted as part of a standard DSM2 2004 simulation. The work related to investigating the Jones Tract levee failure in DSM2 was already incorporated into the 2004 South Delta Temporary Barriers annual report (Suits et al., 2005) and will be distributed to other DSM2 users via the DSM2 Users Group.

Some of the important modeling issues that came up in the process of this work included:

- Some events, such as floods and levee breaks, may require that small time-steps be used in order to avoid numerical instabilities in DSM2. This is an issue that other models may or may not have, but does serve as an important reminder to the appropriateness of scale (both temporal and physical) in numerical modeling.

- Fortunately for 2004 short- and long-term forecasting modeling efforts, the Jones Tract levee break did not result in a significant change in the Martinez boundary condition. The first step in the historical simulation was to examine the stage and salinity boundary condition at Martinez. There was no apparent impact in either of these parameters at Martinez, meaning that the standard tools used to forecast Martinez stage and salinity could be used in this particular situation. However, had the break occurred at a location closer to Martinez, it is possible that use of these standard forecasting assumptions may not be valid.

- The system-wide response to short-term events might not be completely driven by the events themselves, but also may depend upon the antecedent conditions and the short- and long-term management responses to those events. In the case of Jones Tract, the ratio of San Joaquin River compared to Sacramento River water in the Central Delta at the time of the levee break was high because of the 2004 VAMP flows and export curtailments. Had the levee break occurred at a different time, the system response may have been different. Analytical tools like DSM2 are useful in evaluating these sorts of responses, and could even be used to access what would have happened if Jones Tract had flooded in May or July.

- Unfortunately, the amount of hydrodynamic data collected at the Jones Tract levee break and throughout the Delta were limited. For example, the new Coney Island CDEC stage station only went online in late June 2004. This station would have provided important data on the Delta water level impacts near Clifton Court. The Old River at Rock Slough water quality data were available during the break, but the flow information for this location was not available for half of 2004. While it is possible to infer some information from the changes in the EC at this location, the ability to relate hydrodynamic and water quality information at the same location is critical in gaining a more complete understanding of the system-wide impacts.

- The water quality data collected throughout Jones Tract and in Clifton Court were instrumental to this analysis. This event represents the first time that detailed organic carbon and EC data were collected from the large scale flooding of a Delta island rich in organic carbons. By combining a hydrodynamic, water quality, and fingerprinting analysis with large data sets, it was possible to validate and improve the general understanding of the Delta.

- The comparison of modeled and observed DOC through the end of January 2005 (that is, after the end of the Jones Tract pump-off) highlighted the importance of refining the water quality boundary conditions. In this case, the San Joaquin River DOC boundary condition was created based on grab samples. Fewer grab samples were taken in the winter months, meaning it is possible that changes in the San Joaquin River DOC were not reflected in the DSM2 boundary conditions.

3.11 References

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Chapter 4: Sensitivity of DSM2 Temperature Simulations to Time Step Size

Author: Hari Rajbhandari

4 Sensitivity of DSM2 Temperature Simulations to Time Step Size

4.1 Introduction

Computational time steps are important considerations when conducting historical or planning simulations. Increasing the time step reduces the amount of time needed to run the simulation, but it also reduces the ability to accurately represent phenomena with diurnal variation. The goal of the current analysis was to determine the range of time steps in Delta Simulation Model II-QUAL (DSM2-QUAL) that could be used for different types of temperature studies without compromising computational stability and hence the accuracy of the results.

In developing an appropriate numerical scheme for DSM2-QUAL, numerical characteristics of the transport scheme were considered. Lagrangian box models such as DSM2-QUAL are most accurate when computational time steps are small enough to adequately define the important time variations of flow and concentration. Advantage was taken of such small time steps by employing a Modified Euler method to update temperature and reactive constituent concentrations. This method achieves sufficient accuracy when time steps are relatively small (Rajbhandari, 1995). In the approximation in DSM2-QUAL, the Taylor series is truncated after the second order term, so the time steps should not be large.

4.2 Methodology

The time steps tested were 5, 15, 30, and 60 minutes with all the other input variables set to the standard values normally used with DSM2 simulations. The run length was set to 4 years and 5 months. As is typically done in all DSM2 simulations conducted by the Department of Water Resources, the hourly averaged flows generated by HYDRO were used as hydrodynamic input to QUAL.

A 15-minute time step was used for all simulations of DSM2-HYDRO. The study of the sensitivity of simulated temperature to computational time step was based on varying only the QUAL execution time step. For most studies, QUAL is run on a 15-minute time step, which is the condition under which DSM2 was calibrated for temperature (Rajbhandari, 2001).

Test simulations were conducted using the 4.4-year calibration/validation period of July 1996 through November 2000 (Rajbhandari, 2003), but simulation results are shown for only the 1998–2000 period in this report. Simulated temperature was generated at hourly averaged values because DSM2 is typically used to produce output in 15-minute, 1-hour, or daily average values. An hourly output can accommodate output from both the 30-minute and 60-minute time steps. Also, the field data, even those that are monitored continuously, are usually reported as hourly averaged values. However, smaller time steps are usually required to minimize the error due to numerical schemes as described earlier.

4.3 Simulation Results

In the following analysis, temperature simulated using a 15-minute time step was used as the standard. Figure 4.1 presents simulated temperature for the period of July 1996 through January 2000 near the Rough and Ready Island station in the San Joaquin River. A comparison of simulated temperature using a 15-minute time step to field data was discussed in a previous report describing extension of the DSM2 calibration period (Rajbhandari, 2003) and is presented in Figures 4.2 and 4.3 for reference.

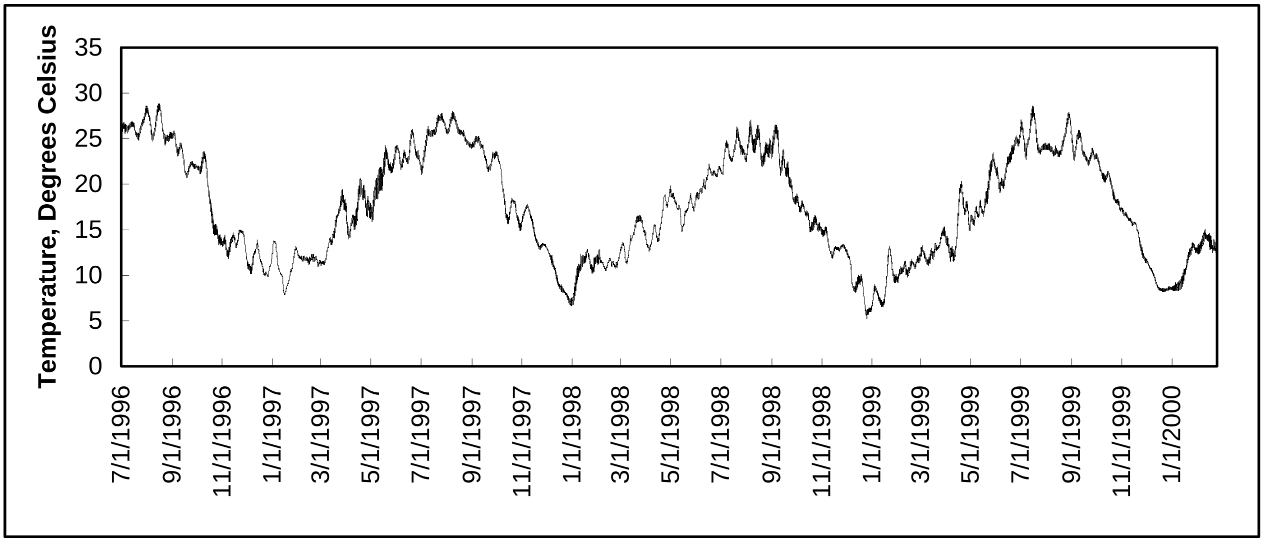

Figure 4.1: Hourly Averaged DSM2-Simulated Temperature in San Joaquin River at Rough and Ready Island Using a 15-Minute Time Step.

Hourly averaged temperature based on time-steps of 5, 15, 30, and 60 minutes were compared (Figures 4.1, 4.2, 4.3, 4.6, and 4.7). Because the temperatures were very close, the differences in simulated temperature were also plotted in the figures shown below (Figures 4.4, 4.5, and 4.8).

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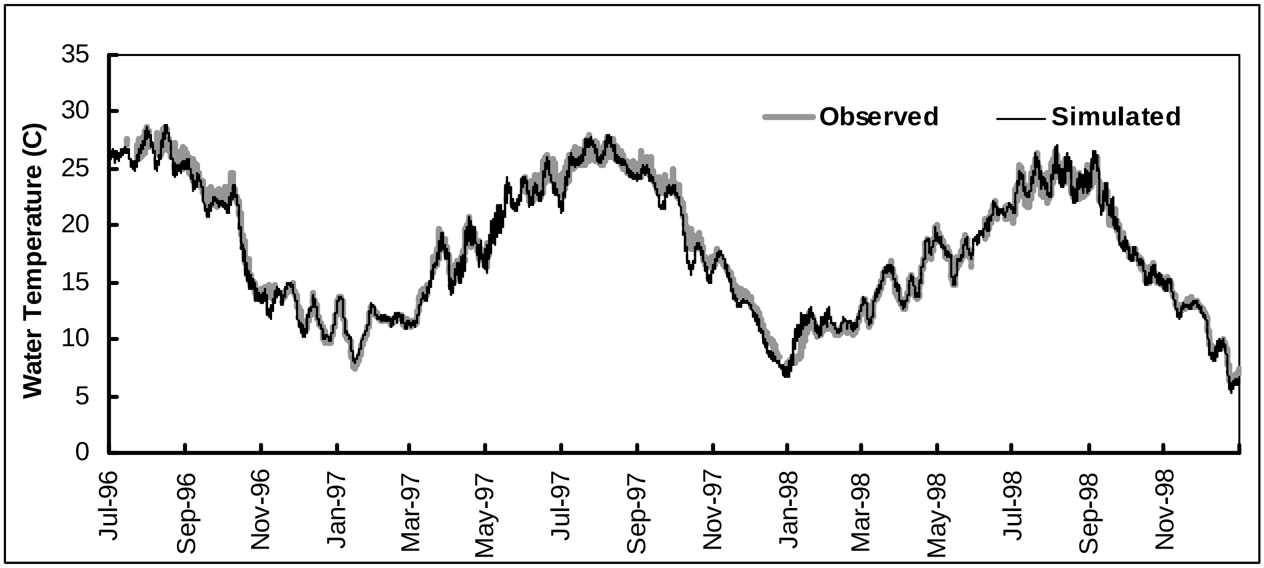

Figure 4.2: Water Temperature in San Joaquin River at Rough and Ready Island, 1996–1998.

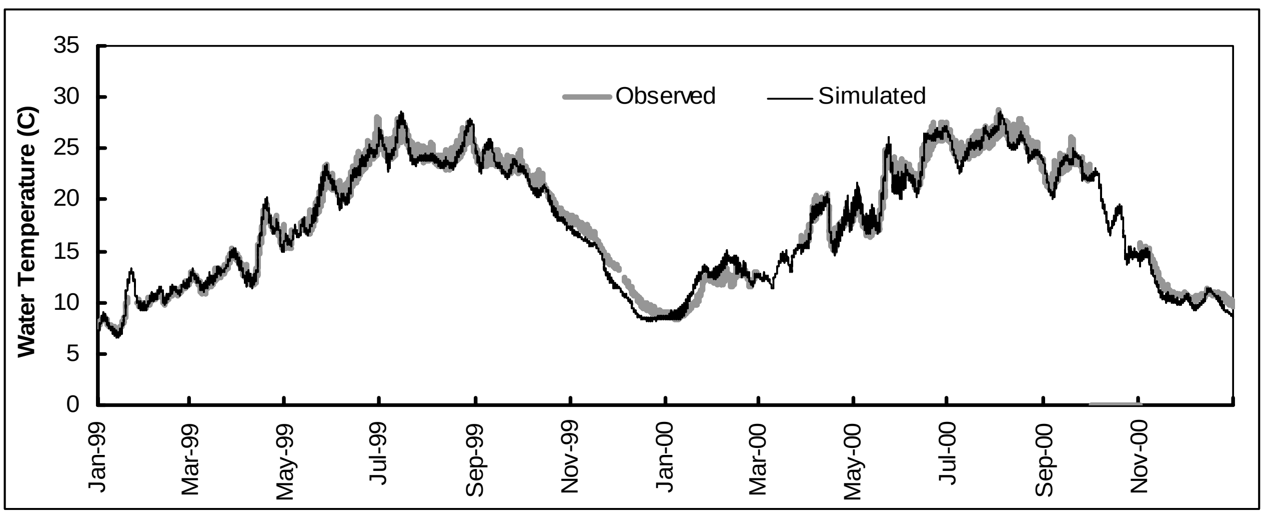

Figure 4.3: Water Temperature in San Joaquin River at Rough and Ready Island, 1999–2000.

In general, hourly temperatures are much closer to each other when generated using 15-minute and 5-minute steps than when using 15-minute and larger time steps. The differences between temperatures for the two smaller time steps during the simulation period are relatively small (Figure 4.4), being less than 0.2 degrees Celsius for almost the entire simulation period. On only 12 occasions in 1998 and 6 instances during 1999 through 2000 were temperature differences greater than 0.5 degrees. Differences were below 1 degree Celsius for the entire simulation period.

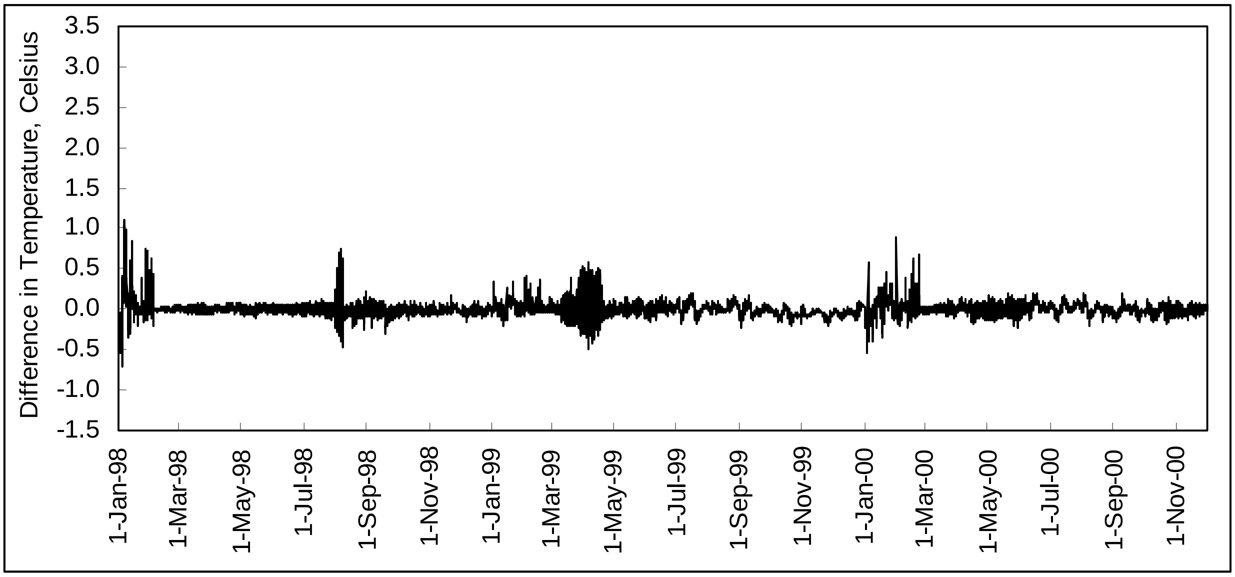

Figure 4.4: Difference in Simulated Hourly Averaged Temperature in San Joaquin River at Rough and Ready Island Using 5- and 15-Minute Time Steps.

The differences in simulated hourly temperature based on 15-minute and 30-minute time steps are at times large (Figure 4.5). For most of the simulated period, the differences are within 0.3 degrees Celsius. For 8 instances each in 1998 and 2000 and 3 instances in 1999, the differences were greater than 0.5 degrees Celsius. Larger differences of about 3 degrees are further examined in the detailed hourly plots shown in Figures 4.6 and 4.7.

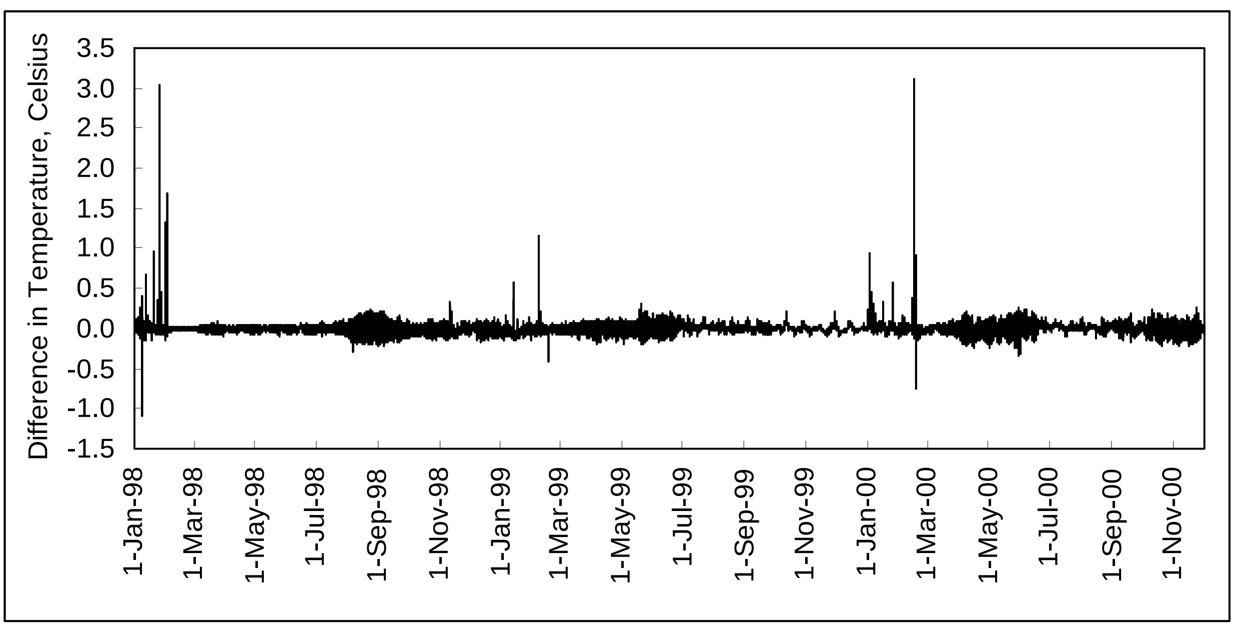

Figure 4.5: Difference in Simulated Hourly Averaged Temperature in San Joaquin River at Rough and Ready Island using 15- and 30-Minute Time Steps.

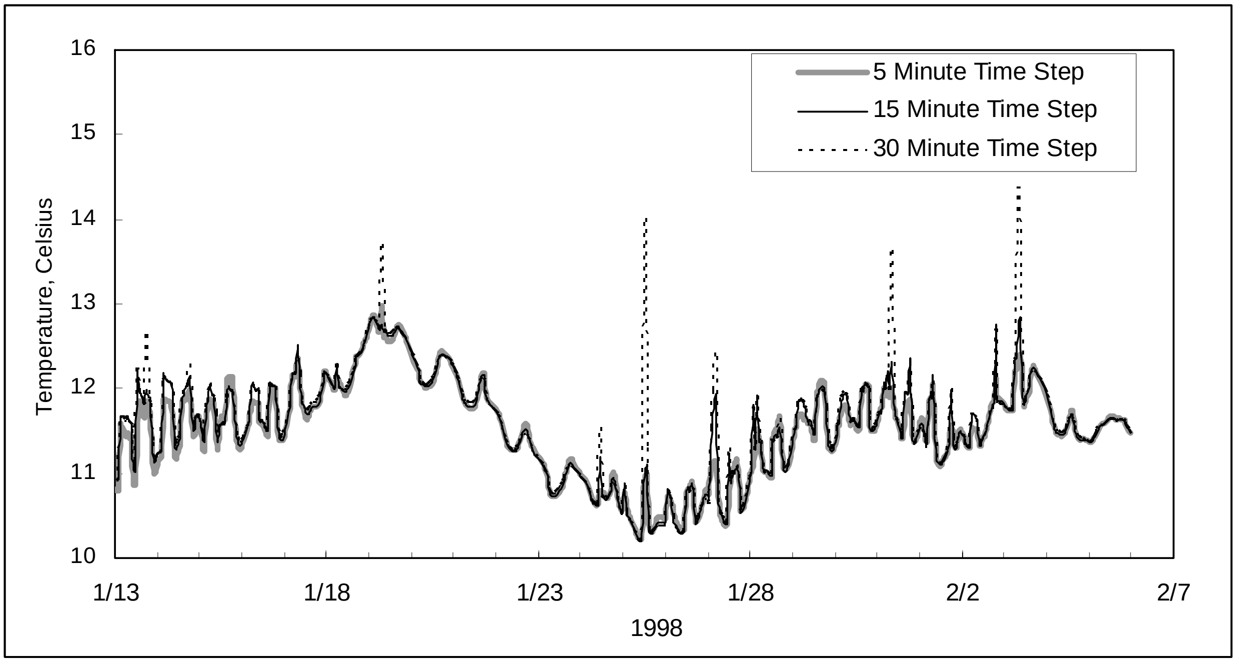

Figure 4.6: Sensitivity of Simulated Hourly Averaged Temperature in San Joaquin River at Rough and Ready Island Using 5-, 15-, and 30-Minute Time Steps, Jan and Feb 1988.

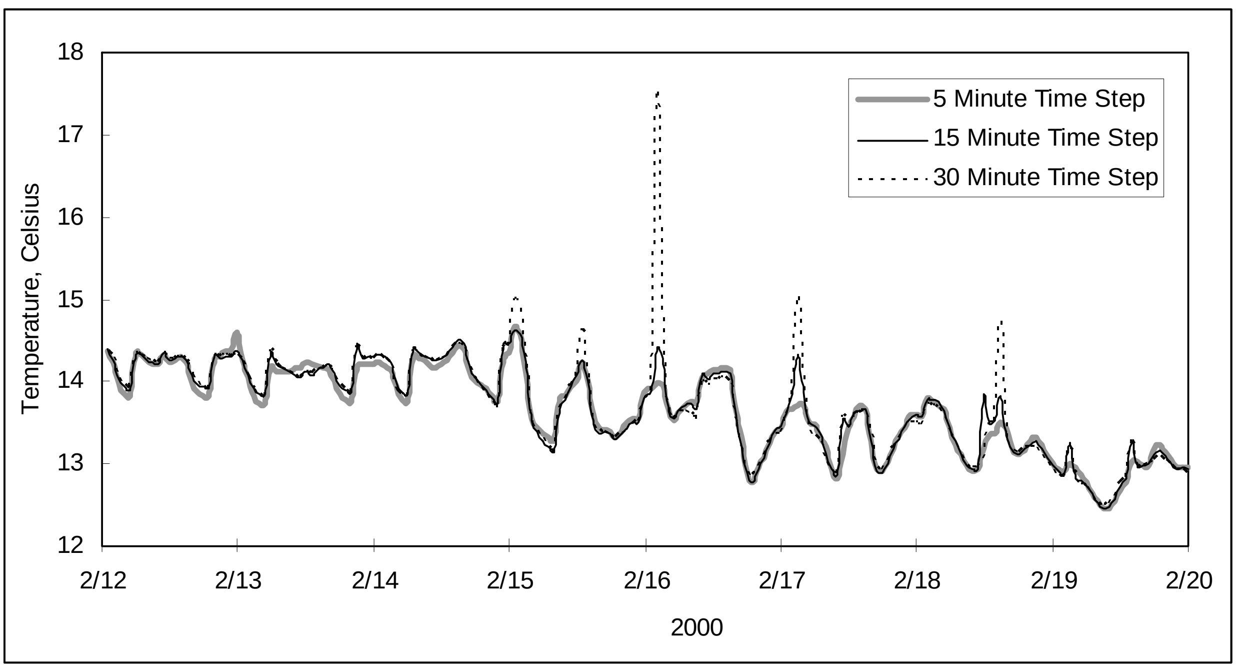

Figure 4.7: Sensitivity of Simulated Hourly Averaged Temperature in San Joaquin River at Rough and Ready Island Using 5-, 15-, and 30-Minute Time Steps, Feb 2000.

These plots focus on a few days of the simulation period to highlight the larger differences in temperatures between the 15-minute and 30-minute time steps ranging from 0.7 to 1.7 degrees Celsius on 5 occasions during the period 1998 through 2000. The largest differences of 3 degrees Celsius are noted on 2 occasions: January 25, 1998 and February 16, 2000. When comparing simulated to observed data, it is apparent that the larger temperatures resulting from the 30-minute time steps are not realistic and are likely a result of numerical errors.

Figure 4.8 displays the differences in temperature using the time steps of 15 and 60 minutes. These differences are similar to those described earlier for the comparison of the results of using a 30-minute time step to those when using a 15-minute time step. Because a similar argument holds for this case, the detailed hourly plots as shown in Figures 4.6 and 4.7 are not included for the 60-minute simulation.

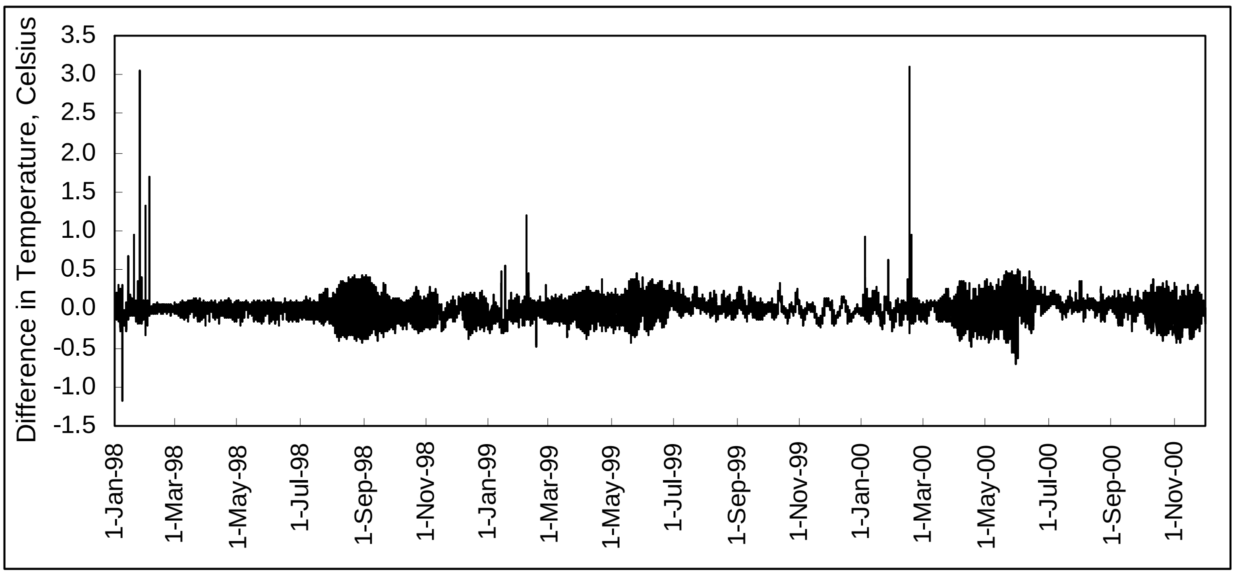

Figure 4.8: Difference in Simulated Hourly Averaged Temperature in San Joaquin River at Rough and Ready Island Using 15- and 60-Minute Time Steps.

4.4 Daily Averaged Data

DSM2 planning study water quality results are often reported as a daily average because the dispersion factors in DSM2-QUAL have been calibrated to daily average salinity. Thus, it is pertinent to examine the temperature sensitivity to computational time step in terms of daily-averaged temperatures. Figures 4.9 and 4.10 present the daily averaged temperatures from DSM2 using 5-, 15- and 30-minute time steps. As expected, the simulated daily-averaged temperatures using 5- and 30-minute time steps are close to those based on a 15-minute time step. The magnitudes of the differences were less than 0.1 degree Celsius for most of the simulation.

Although the simulated temperatures will typically be more accurate using smaller time-steps than larger time steps, the differences are generally smaller between temperatures using the 30-minute and the 15-minute time steps (Figure 4.9) than between temperatures using the 15-minute and the 5-minute time-steps (Figure 4.10). This apparent counterintuitive result is most likely an artifact of averaging values over an hour.

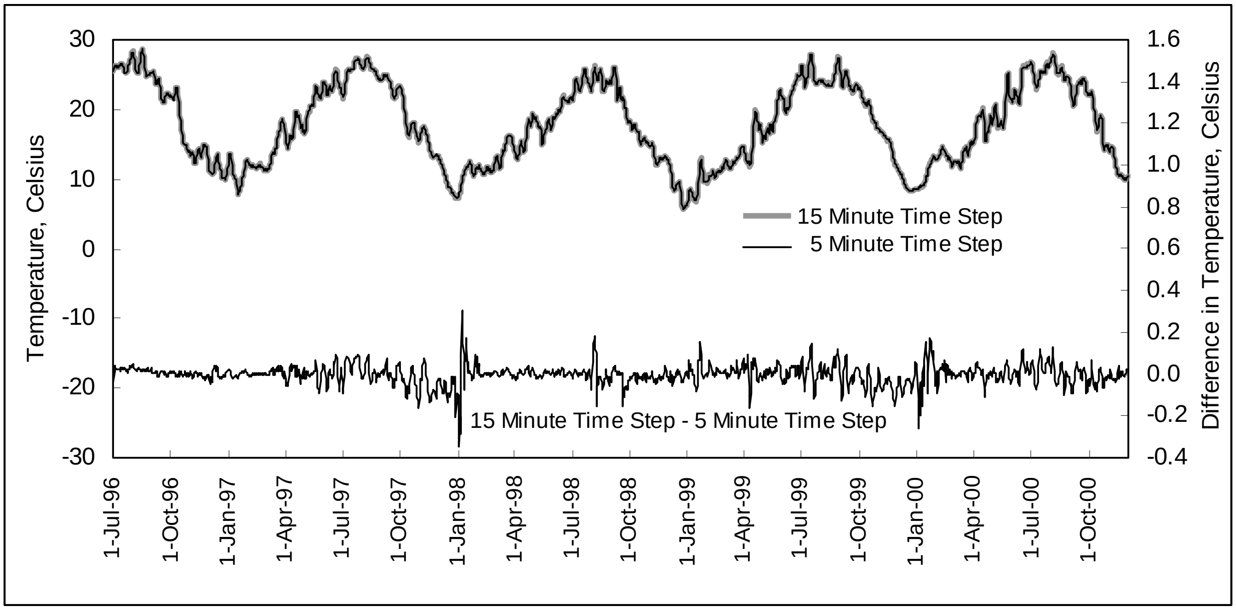

Figure 4.9: Daily Averaged DSM2 Temperature in San Joaquin River at Rough and Ready Island Using 5- and 15-Minute Time Steps.

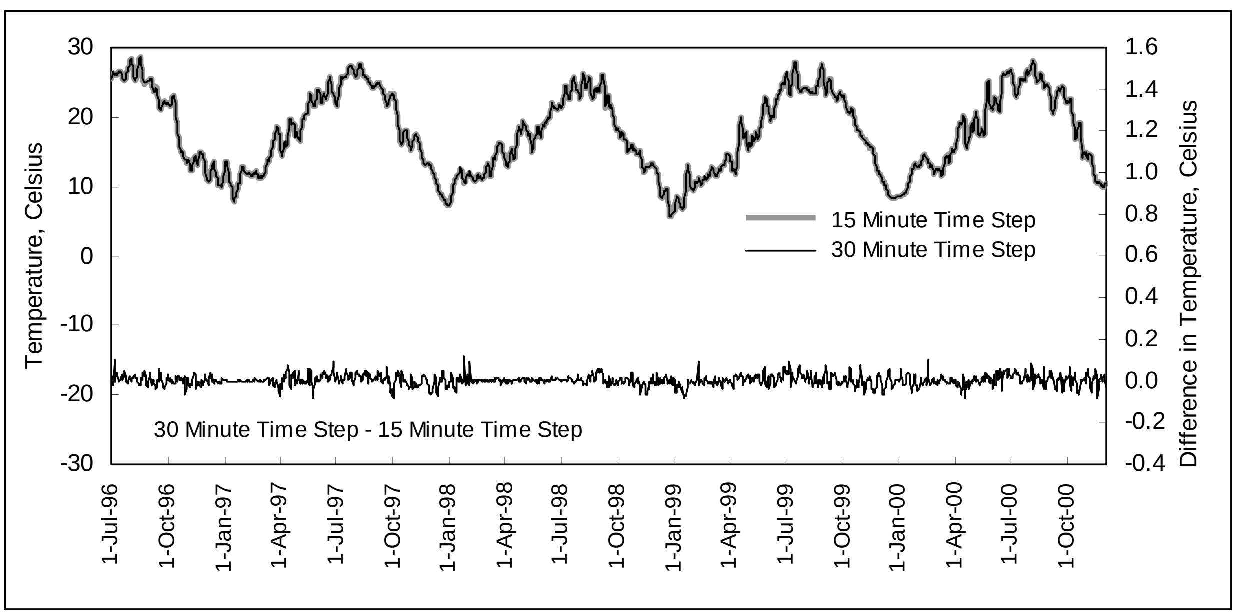

Figure 4.10: Daily Averaged DSM2 Temperature in San Joaquin River at Rough and Ready Island Using 15- and 30-Minute Time Steps.

4.5 Computer Time

Temperature is normally simulated by DSM2-QUAL in the context of simultaneously simulating 10 other constituents in the process of modeling dissolved oxygen. The computer Central Processing Unit (CPU) time needed to simulate 4.4 years of temperature and the 10 other constituents was studied and is provided in Table 4.1.

Table 4.1: DSM2-QUAL Run Time vs. Time Step Size for 4.4 years of Simulation of Temperature Plus 10 Other Constituents.

Time Step in Minutes	CPU Time on Xeon 3.06 GHz
5	7 hours, 6 minutes
15	2 hours, 16 minutes
30	58 minutes
60	24 minutes

4.6 Conclusions

The time steps chosen for the sensitivity analysis of DSM2 temperature simulations were based on the numerical aspects of the model and on practical considerations of computer execution time. While it is tempting to use larger time steps to reduce run time, important considerations of underlying numerical schemes are crucial to consider. The current analysis indicates that the time step size of 15 minutes is most suitable; however, time-step sizes of 30 minutes or 60 minutes may be acceptable for certain studies because unrealistic solutions occurred in only a very few instances. A DSM2 user should check the results for anomalies if these larger time steps are used. It is important to note that this analysis has been conducted for temperature but not for other constituents, and these constituents should also be evaluated. A previous study by Lee and Nader (1997) did focus on time step sensitivity in QUAL to modeled salinity.

The time steps of 30 minutes or 60 minutes may be especially useful for screening runs or simulating a long simulation period, such as a CALSIM-based 73-year period. For example, a shorter run time could certainly be helpful for studies that examine the effect of climate change on the Delta.

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

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Chapter 5: Estimation of Electrical Conductivity at Martinez for Sea Level Rise Conditions

Authors: Jamie Anderson and Aaron Miller

5 Estimation of Electrical Conductivity at Martinez for Sea Level Rise Conditions

5.1 Introduction

Historical data of water levels (stage) at Golden Gate over the past century indicate a long-term trend of increasing annual average sea level (Figure 5.1). From 1900 through 2003, the average annual water level at Golden Gate rose about 0.08 inches per year with a total increase of 8.15 inches. Such increases may be influenced by climate change factors like thermal expansion of the ocean and melting of the polar ice caps. Model projections indicate a median sea level rise (SLR) of 1.6 foot over the next 100 years due to climate change (DWR, 2005). In response to these historical trends and future projections, the Department of Water Resources' planning models are being applied to assess potential impacts of SLR on the hydrodynamics and water quality of the Sacramento-San Joaquin Delta.

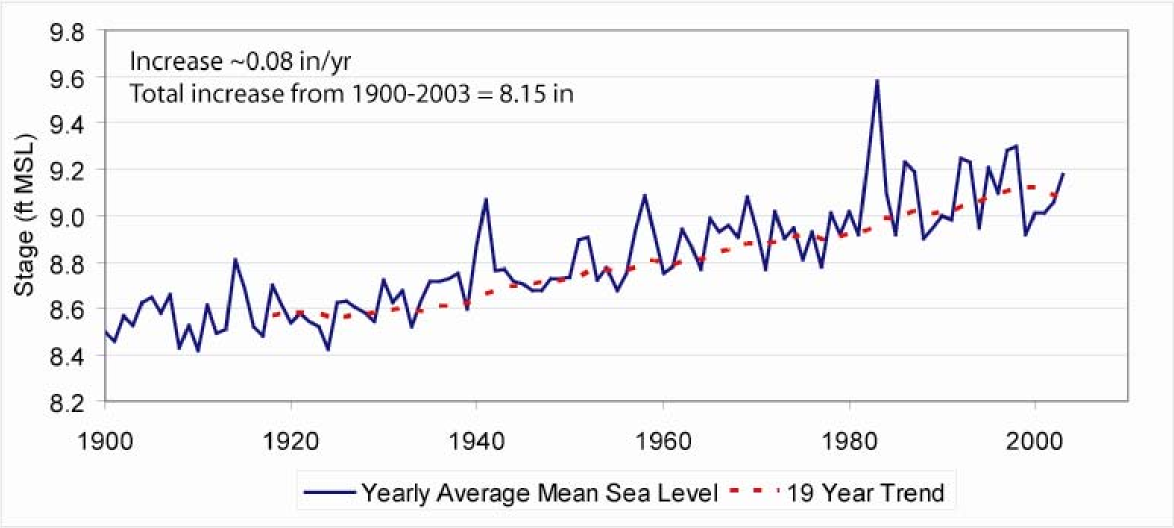

Figure 5.1: Historical Annual Mean Sea Level at Golden Gate, 1900–2003.
(Source: Maury Roos, DWR State Hydrologist).

Modeling SLR impacts on Delta water quality requires assessment of potential changes to salt intrusion into the Delta. To investigate SLR impacts using the Delta Simulation Model 2 (DSM2), assumptions may be made regarding this salt water intrusion to create the downstream boundary condition at Martinez. This chapter presents two methods for estimating electrical conductivity (EC) concentrations at Martinez for DSM2 simulations of SLR conditions:

- Modified G-model relationship using an astronomical tide and Net Delta Outflow (NDO), and
- Regression relationship between base EC and 1-foot SLR EC.

5.2 DSM2 Downstream Boundary

Projections of SLR for San Francisco Bay are typically provided at Golden Gate. Because the DSM2 model has its downstream boundary at Martinez (Figure 5.2), the effects of SLR on water levels and salinity at Golden Gate have to be translated to Martinez in order to assess impacts by using DSM2 (Figure 5.3). This paper presents two methods for determining SLR boundary conditions at Martinez. For both methods the tidal stage at Martinez is uniformly increased by the amount of SLR. The difference between the two methods is in the specification of the EC boundary condition at Martinez as follows:

- Martinez EC determined from a modified G-model using astronomical tide and NDO, or
- Martinez EC determined from an EC regression relationship developed from multi-dimensional modeling simulations using Resource Management Associates (RMA) models.

Both methods employ the same modified stage boundary condition at Martinez to represent SLR, which results in the same additional amount of water entering the Delta during the tidal exchange. However, the boundary EC at Martinez will be different for each method. The EC associated with the water carried into the Delta will be lower in the modified G-model and NDO method than in the RMA-based regression. In the first method, the increase in stage at Martinez will result in more salinity entering the Delta, but this method does not account for the increased water level in the San Francisco Bay that is bringing more EC to Martinez. The second method indirectly accounts for the increased tidal exchange between San Francisco and Martinez resulting in higher EC concentrations at Martinez. Although the tidal exchange simulated at Martinez in the second method is identical to the amount simulated in the first method, the higher EC in the second method at Martinez results in greater amounts of salt entering the Delta from the downstream boundary.

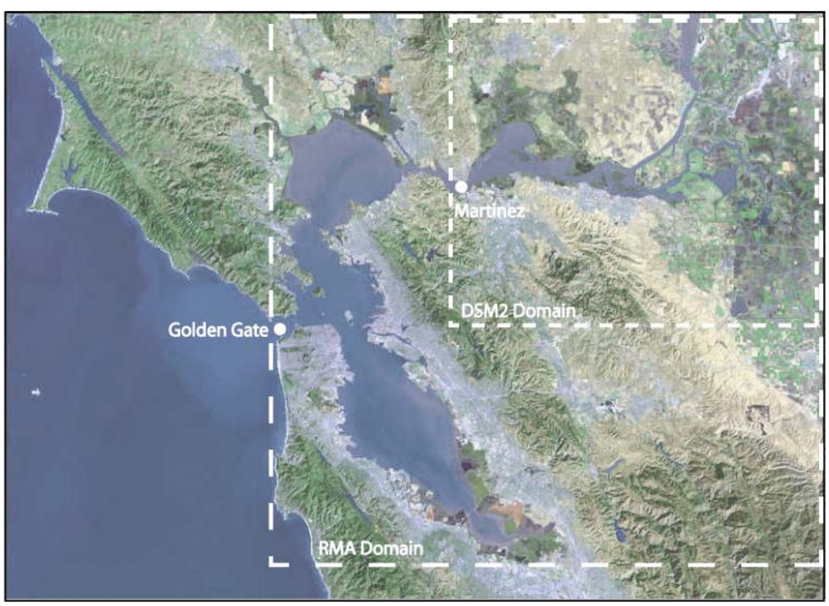

Figure 5.2: Map of San Francisco Bay and the Delta with RMA and DSM2 Model Boundaries.
(Satellite image from US Geological Survey).

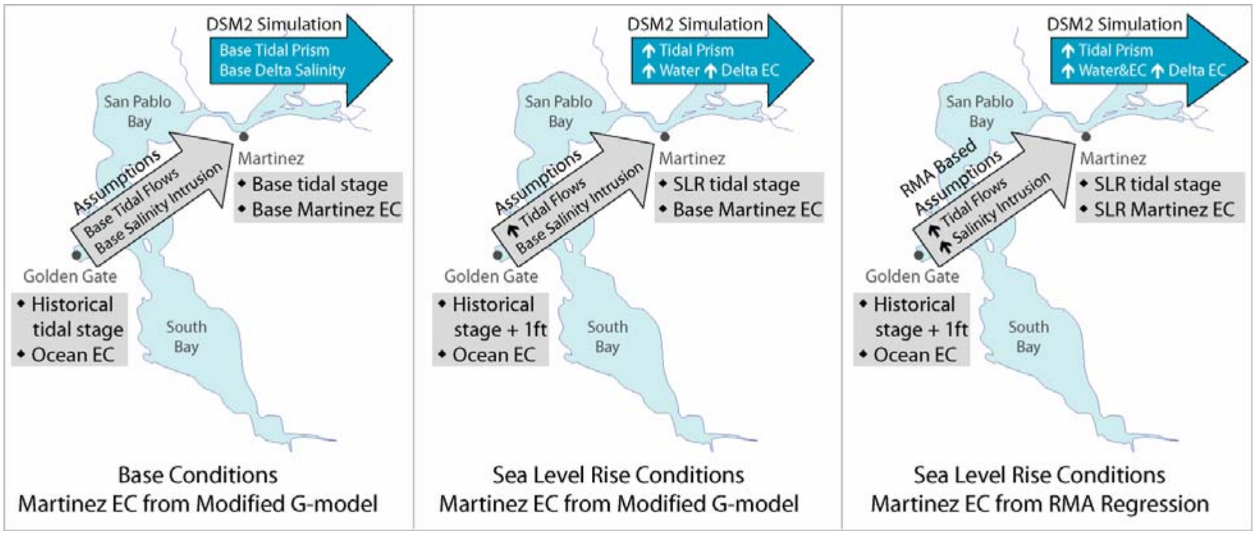

Figure 5.3: Modeling Methods for Simulating Sea Level Rise in the Delta.

The two methods are described in the following sections of this chapter. DSM2 planning studies are typically 16-year simulations that represent hydrologic variability reflective of water years 1976–1991. For these planning studies, Delta inflows and exports are often provided by output from planning models such as the CALSIM II water allocation model.

5.3 Estimating Martinez EC for SLR Using the Modified G-model

DSM2 planning studies for non-SLR conditions use a modified G-model to compute the salinity boundary condition at Martinez. The G-model provides a conceptual-empirical representation of daily-averaged salinity transport along the main stem of the Sacramento River (Denton and Sullivan, 1993). The G-model has been modified to produce a 15-minute time series of EC at Martinez based on a 15-minute astronomical tide and a daily NDO (Ateljevich, 2001). The hydrodynamics of the Delta are represented by the daily NDO, which is the sum of the Delta inflows minus the sum of the Delta exports. The general shape of the tidal signal is provided by the 15-minute astronomical tide. Thus, the modified G-model provides an empirical estimate of a 15-minute EC time series at Martinez that reflects the hydrodynamics and the tidal variation in EC. This section describes the application of the modified G-model for SLR simulations.

The current DSM2 planning study methodology (Shrestha, 2002) can be used to simulate any level of SLR by:

1) Modifying the tidal stage boundary condition at Martinez to reflect SLR conditions, then
2) Applying the modified G-model to determine Martinez EC based on an astronomical tide and NDO.

To date for SLR studies, the tidal boundary condition at Martinez has been determined by uniformly increasing the historical tidal stage by the desired amount of SLR. This method assumes that SLR changes the amplitude of the tide uniformly but does not alter the shape of the tidal signal.

Using the modified G-model to estimate EC at Martinez provides a conservative (lower EC) estimate of salinity intrusion due to SLR because the model does not consider parameters that reflect increased salt intrusion from the ocean to Martinez. The input parameters to the modified G-model are an astronomical tide and NDO. Because NDO is computed as the sum of inflows minus the sum of exports, the NDO does not change for scenarios in which sea level is increased without any compensating adjustments of system operations (a typical method for assessing impacts). The modified G-model is an empirical model, not a physically-based model. Therefore, it is not an appropriate application of the G-model to apply a physical change to its input such as offsetting the astronomical tide by a constant value to represent SLR.

Thus for impacts assessments in which sea level is increased and operations are not modified, the modified G-model provides identical EC concentrations at Martinez for both base and SLR scenarios. In SLR scenarios, increases in Delta EC compared to the base conditions are due only to increased tidal flows from the ocean. This method does not account for additional salt transported from the ocean to Martinez.

5.4 Estimating Martinez EC for 1-foot SLR Using an EC Regression Relationship

A methodology was developed for estimating the EC boundary condition at Martinez for DSM2 planning studies of SLR. It considers additional salt intrusion from the ocean (Figure 5.4). This methodology uses multi-dimensional RMA models to simulate salt transport from Golden Gate to Martinez for base and 1-foot SLR simulations for a one-year period. A regression equation was developed between the simulated Martinez EC for the base and 1-foot SLR scenarios. This regression equation can be used to compute the EC boundary condition at Martinez for longer term DSM2 planning studies of 1-foot SLR conditions. Details of this methodology and the resulting EC regression equation are presented in the following sections of this chapter.

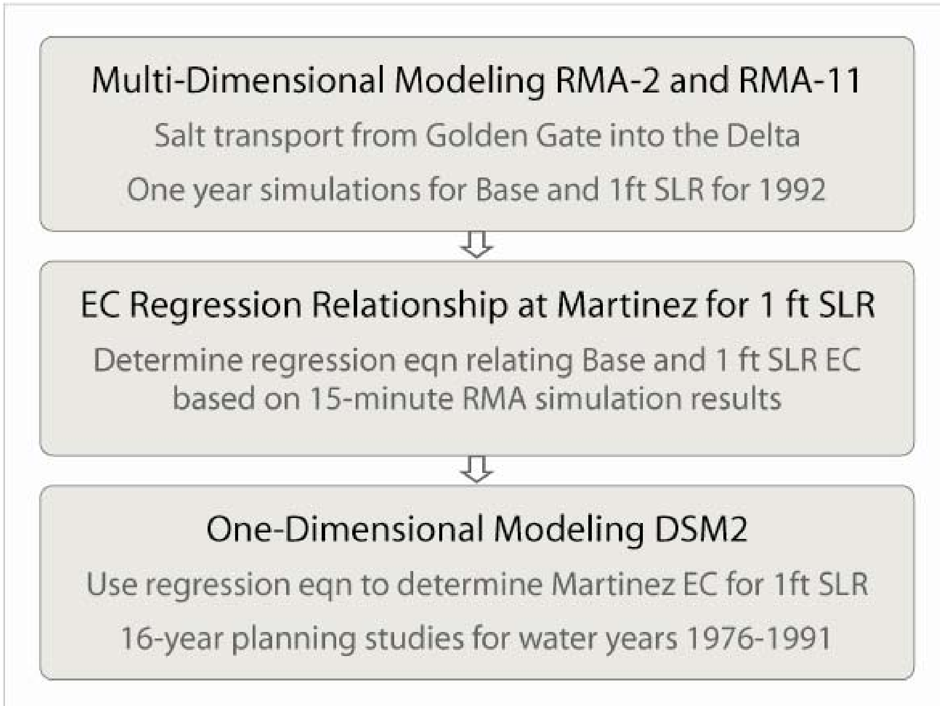

Figure 5.4: Multi-Dimensional Modeling Methodology for Simulated SLR in the Delta.

5.4.1 Multi-Dimensional Modeling with RMA-2 and RMA-11

Simulation of flows and salt water intrusion due to SLR was conducted using multi-dimensional models from RMA. For the RMA models, the San Francisco Bay-Delta system's downstream boundary was the ocean boundary at Golden Gate (Figure 5.2). In the RMA models, San Francisco Bay and part of the western Delta have a two-dimensional depth averaged representation, and the rest of the Delta has one-dimensional channels. Hydrodynamics (flows, water levels, etc.) were simulated using RMA-2. Results from RMA-2 provided the input flows for the water quality model RMA-11.

Both base (approximately historical) and 1-foot SLR conditions were simulated using the RMA models (Figure 5.5). Because multi-dimensional modeling is computationally expensive, a one-year simulation period representing historical Delta inflows and exports for 1992 was selected for this study. The study period was relatively dry with one large storm event during the spring (Figure 5.6). A dry simulation period was desired because impacts of salt water intrusion would be greatest during low Delta inflows. The large spring storm also provided a range of flow conditions. An SLR of 1 foot was chosen for this study because that value is within the range of projections of SLR over the next century.

Additional rough estimates of impacts of other values of SLR can be estimated by scaling the results for a single foot of SLR. Such rough scaling of 1-foot SLR results does not replace more thorough impacts assessments.

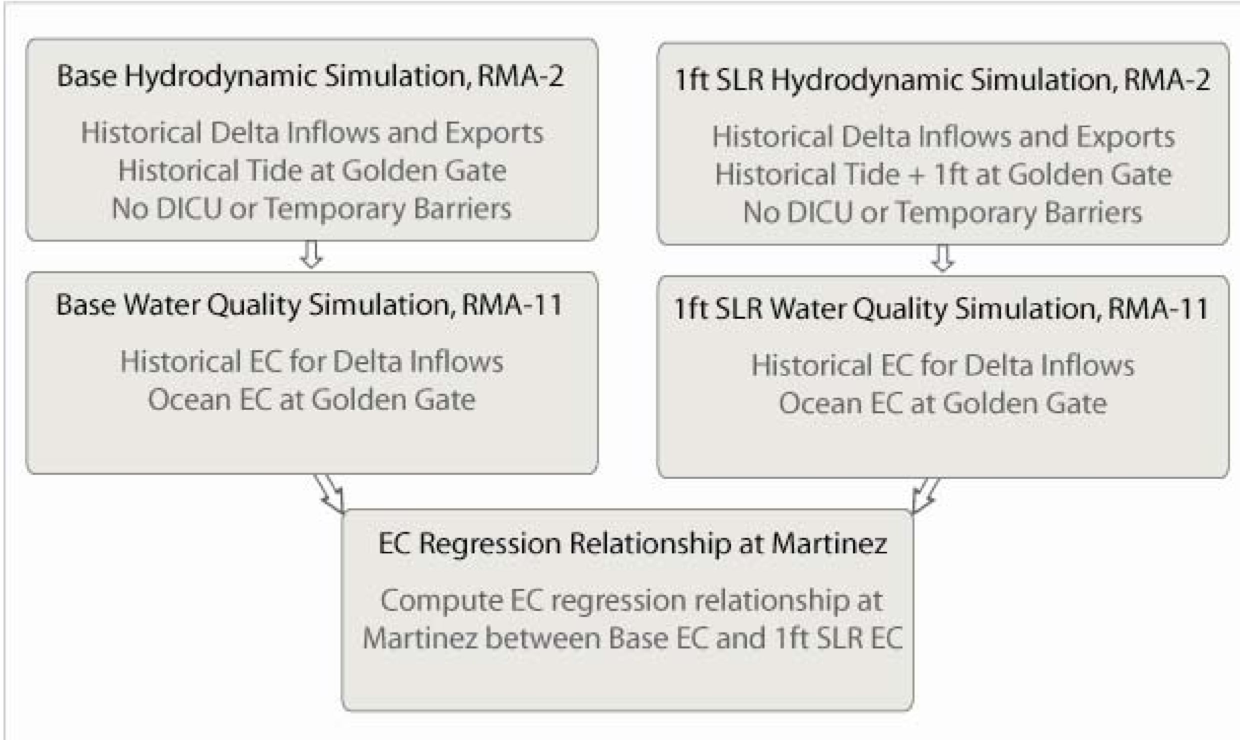

Figure 5.5: Multi-Dimensional RMA Modeling to Develop 1-foot SLR EC Relationship at Martinez.

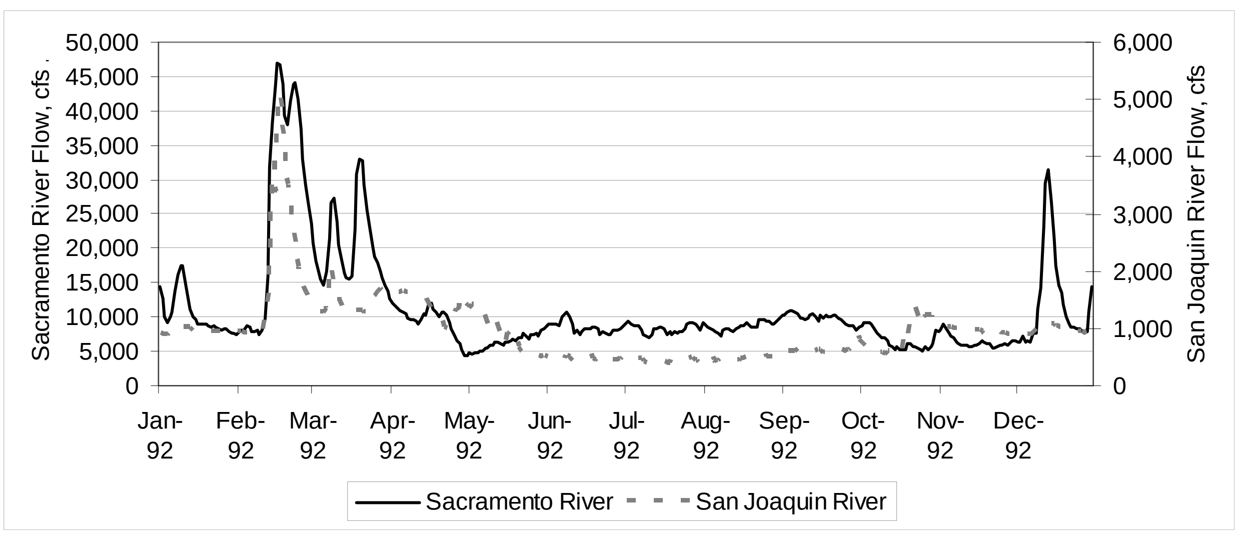

Figure 5.6: Sacramento and San Joaquin River Inflows for 1992.

The following assumptions were made for the RMA simulations:

- Historical tidal stage at Golden Gate was increased uniformly by 1 foot,
- Ocean salinity was not affected by SLR [the same EC boundary condition of a constant ocean salinity was applied for both the base and 1-foot SLR scenarios],
- Historical Delta inflows and exports were not modified to mitigate for salt water intrusion due to SLR [historical Delta inflows and exports were used for both the base and 1-foot SLR scenarios],
- Agricultural return flows did not significantly affect EC at Martinez [Delta island diversions and return flows were not simulated],
- Temporary agricultural and fish barriers in the South Delta were not simulated, and
- Historical Delta inflows and exports for 1992 provided adequate ranges of flows and EC to develop an EC relationship at Martinez for 1-foot SLR conditions that can be applied for any time period.

5.4.2 EC Regression Relationship

EC at Martinez was simulated for base and 1-foot SLR conditions for 1992 using the multi-dimensional RMA models as described in the previous section. Because the RMA simulations were conducted for a one-year period, it was desired to develop a relationship for EC at Martinez for 1-foot SLR conditions that could be used to compute longer term time series. Several types of regression relationships (for example, linear, polynomial, and exponential) between base and 1-foot SLR conditions were explored for various combinations of EC, change in EC, stage at Martinez, and NDO. This paper presents the regression relationship that had the highest R-squared value for the initial analysis. Additional investigations will continue to explore possible correlations between EC for base and SLR conditions including examining multi-variate regression relationships.

The 15-minute simulated EC at Martinez for both base and 1-foot SLR scenarios were used to develop a linear regression relationship between the base EC and the EC at Martinez associated with a 1-foot SLR (Figure 5.7):

$$MartinezEC_{1\,ft\,SLR} = 1.0022 * MartinezEC_{Base} + 840.87 \qquad \text{[Eqn. 5-1]}$$

Note that this relationship is only applicable for a 1-foot rise in sea level. Because this relationship is linear with a coefficient of nearly 1 (1.0022), Eqn. 5-1 indicates that a 1-foot rise in sea level at Golden Gate corresponds to an approximate increase in EC at Martinez of 840 uS/cm. The base EC at Martinez is highest during low freshwater inflow periods, typically during the summer and early fall. Because the EC at Martinez during those time periods was already high (20,000-35,000 uS/cm), an increase in EC of 840 uS/cm was a relatively small increase (less than 5%). During high freshwater inflow periods when Martinez EC is lower, the percent increase in EC for SLR conditions would be higher. However, salt intrusion is not typically an issue when freshwater inflows are high.

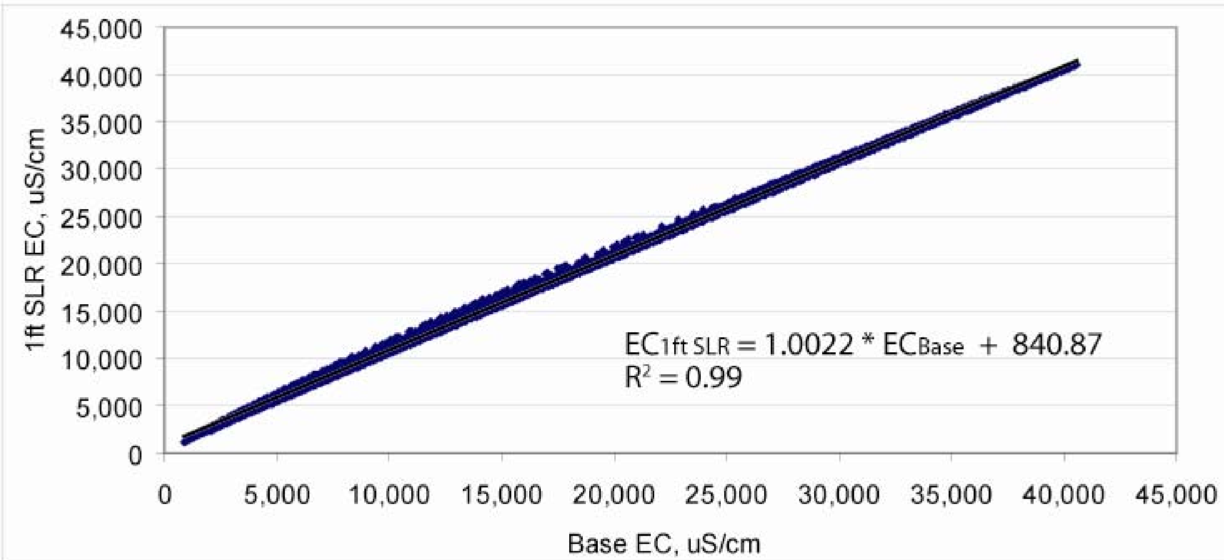

Figure 5.7: Regression Relationship for EC at Martinez for 1-foot Sea Level Rise.

5.4.3 DSM2 Martinez EC Boundary Condition for 1-foot SLR

Typically, DSM2 planning studies are run for a 16-year analysis period representing hydrology from water years 1976–1991 (Oct. 1975–Sept. 1991). For 1-foot SLR simulations, EC at Martinez for the 16-year analysis period can be developed using the regression relationship presented in the previous section of this chapter (Eqn. 5-1). Martinez EC for 1-foot SLR conditions was computed based on Martinez EC for base (non-SLR) conditions (Figure 5.8). Base Martinez EC was computed from the modified G-model using an adjusted astronomical tide and the NDO (Ateljevich, 2001). The regression relationship in Eqn. 5-1 was then applied to the base Martinez EC to compute Martinez EC for 1-foot SLR conditions. The resulting 15-minute time series of EC at Martinez for 1-foot SLR conditions can be used as the downstream boundary condition for DSM2 water quality simulations. Note that in the companion DSM2 hydrodynamic simulation, the tidal stage boundary condition at Martinez should be increased by 1 foot at every time step to represent SLR conditions.

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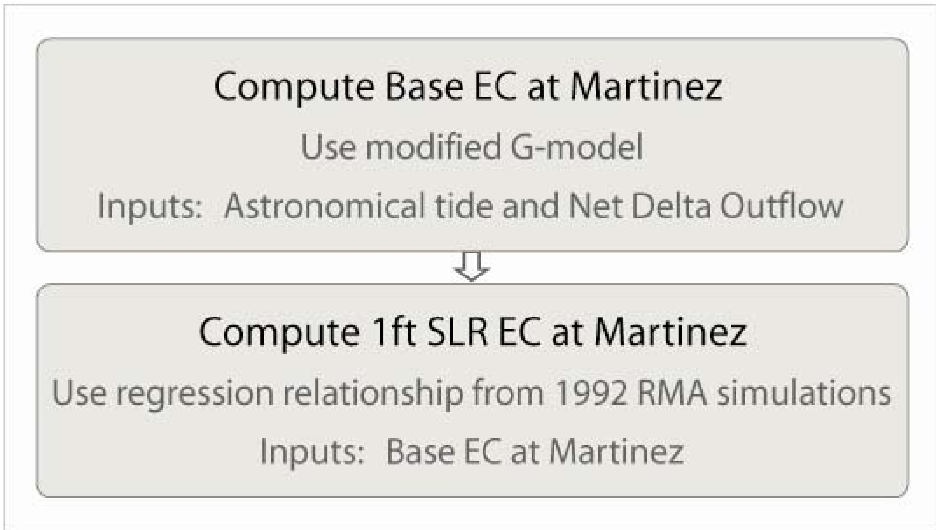

Figure 5.8: Determining Martinez EC for 1-foot SLR from a Regression Equation.

Using the EC regression relationship (Eqn. 5-1) to determine the Martinez EC boundary condition at Martinez for DSM2 planning simulations was based on the following assumptions:

- 1-foot SLR at Golden Gate resulted in approximately 1-foot SLR at Martinez [based on RMA simulation results],
- Tidal stage at Martinez was increased uniformly by 1 foot,
- Historical Delta inflows and exports for 1992 provided adequate ranges of flows and EC to develop an EC relationship (Eqn. 5-1) at Martinez for 1-foot SLR conditions that could be applied for any time period, and
- Base (non-SLR) EC at Martinez was known or could be determined.

5.5 Example DSM2 Results for 1-foot SLR

DSM2 planning simulations were run to illustrate the effects of the two methods of estimating Martinez EC when conducting SLR simulations. For these example simulations, an SLR of 1 foot was used because the EC regression equation only applies to 1-foot SLR conditions. Delta inflows and exports were provided by the CALSIM 2020 Benchmark simulation from October 2003. Three DSM2 studies were conducted as follows:

- 2020 Benchmark (no SLR) [base case];
- 2020 Benchmark with 1-foot SLR, Martinez EC determined from modified G-model; and
- 2020 Benchmark with 1-foot SLR, Martinez EC determined from EC regression (Eqn 5-1).

For the SLR simulations, the tidal stage at Martinez was increased uniformly by 1 foot, and the EC at Martinez was determined by one of the two methods presented in this chapter. All other boundary conditions were identical for the three simulations. The following assumptions were used in these illustrative DSM2 planning simulations:

- Tidal stage at Martinez was increased uniformly by 1 foot for the SLR scenarios,
- EC at Martinez for 1-foot SLR was provided by one of two methods
  - Modified G-model based on an astronomical tide and NDO
  - EC Regression relationship between base EC and 1-foot SLR EC (Eqn 5-1),
- Delta inflows and exports were not modified to mitigate for salt water intrusion due to SLR [Delta inflows and exports were identical for all simulations], and
- Temporary agricultural and fish barriers in the South Delta were not simulated.

For SLR DSM2 planning simulations, the modified G-model method provides a more conservative (lower) estimate of EC concentrations in the western Delta. This method only accounts for higher salinity due to increased tidal flows. Potential higher EC at Martinez due to increased intrusion of ocean water into the Delta is not considered. In contrast, because the EC regression method accounts for increased ocean water intrusion into the Delta, the EC regression method results in higher simulated salinity concentrations in the western Delta. Thus, using both Martinez EC estimation techniques for 1-foot SLR scenarios should bound potential salinity intrusion estimates.

For illustrative purposes, monthly average simulated EC values at Antioch for the three scenarios are shown in Figure 5.9. The differences between Antioch EC for each of the SLR scenarios compared to the base case are shown in Figure 5.10. Monthly maximum, average, and minimum EC concentrations for the 16-year simulation period are presented in Figure 5.11. Maximum monthly average EC concentrations at western Delta locations were higher than the base case in all months for both Martinez EC estimation techniques. The EC regression relationship provided the highest maximum EC estimation. Average monthly EC concentrations were similar for both Martinez EC estimation techniques. During wet periods, EC concentrations in the western Delta were dominated by freshwater inflows, and nearly identical results were produced by either Martinez EC estimation technique.

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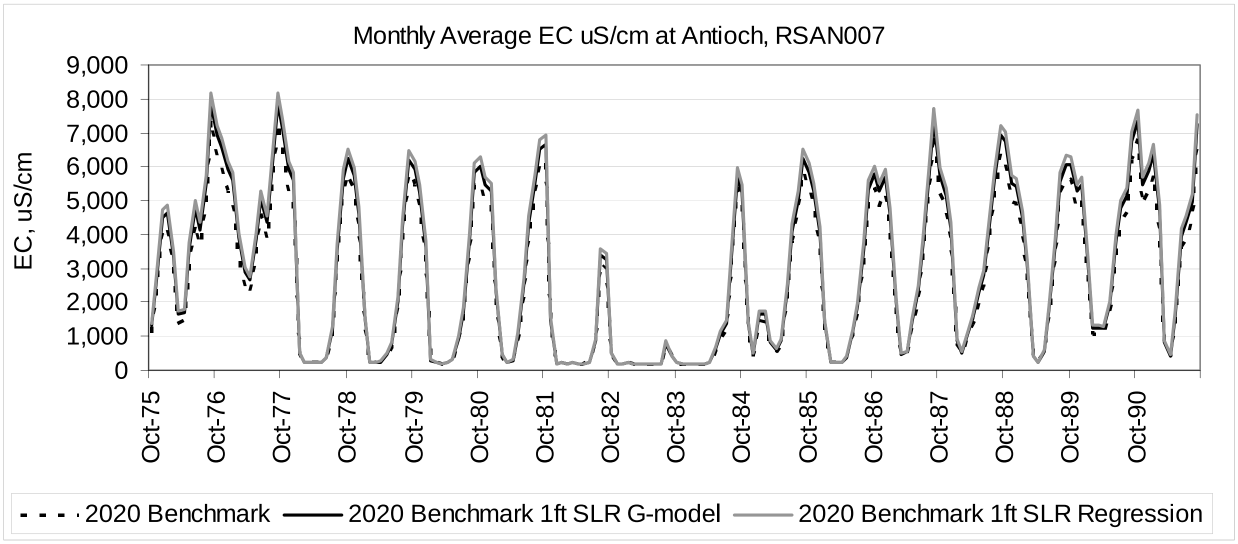

Figure 5.9: Monthly Average Simulated EC at Antioch for 1-foot SLR Scenarios.

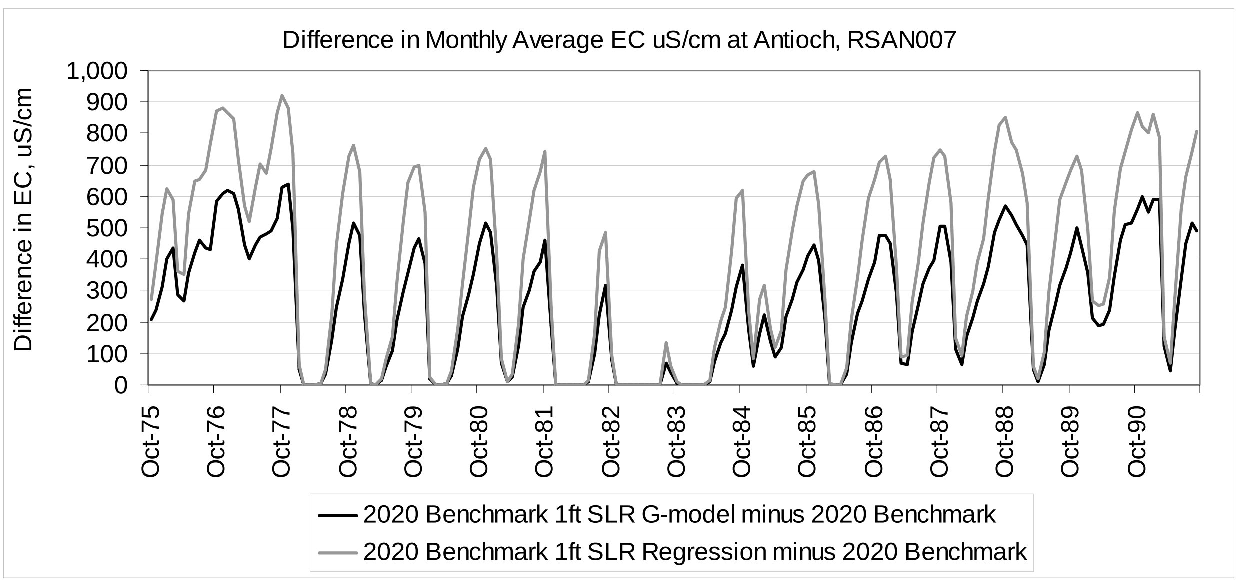

Figure 5.10: Difference in Monthly Average Simulated EC at Antioch for 1-foot SLR Scenarios.

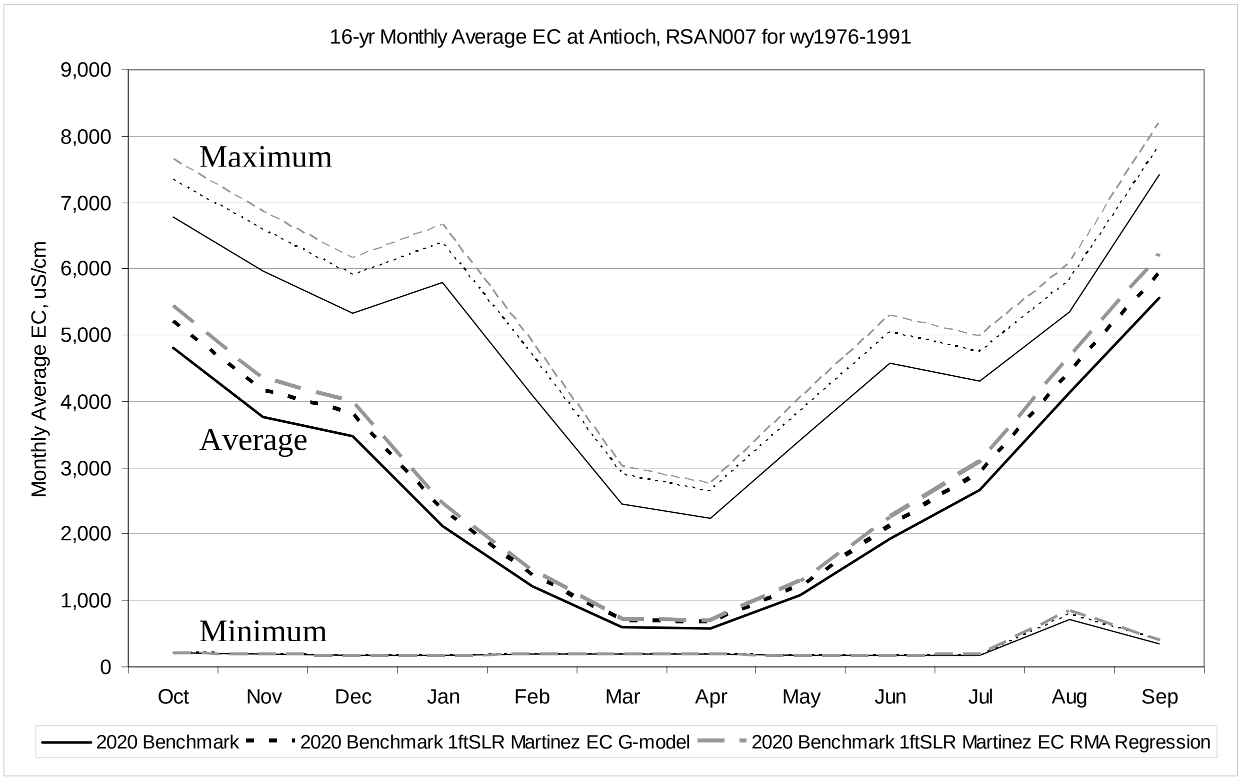

Figure 5.11: 16-Year Monthly Average Simulated EC at Antioch for 1-foot SLR Scenarios.

5.6 Summary

This chapter presents two methods for estimating Martinez EC concentrations for establishing boundary conditions for DSM2 planning studies of SLR conditions: a modified G-model and a 1-foot SLR EC regression equation. Lower estimates of salinity intrusion due to SLR can be calculated using the same modified G-model that is used to calculate Martinez EC for the base conditions. For this method, increased salinity intrusion into the Delta is due only to a larger tidal prism at the downstream boundary that is transporting salinity into the Delta. Higher sea levels at Martinez cause salinity intrusion into the Delta that is due to the increased tidal flows. For higher estimates of salinity intrusion into the Delta due to SLR, the Martinez EC boundary condition can be determined by a regression relationship relating base and 1-foot SLR conditions. For this method, increased salinity intrusion into the Delta is due to both increased tidal flows and increased salinity concentrations at Martinez. Thus, using both methods and comparing the results provides a range of potential impacts of SLR on Delta salinity. The method and major characteristics of each method are summarized below in Table 5.1.

Table 5.1: Summary of Estimation of Sea Level Rise Based EC Techniques.

Use modified G-model to estimate Martinez EC for SLR Scenarios

Method

- ❑ Uniformly increase the tidal stage boundary condition at Martinez to reflect SLR conditions
- ❑ Use base condition Martinez EC (Apply the modified G-model to determine Martinez EC based on an astronomical tide and NDO)

Characteristics

- ❑ Only simulates salt intrusion that is due to increased tidal flows
- ❑ Can simulate any level of SLR
- ❑ Provides a conservative (lower bound) estimate of salt intrusion due to SLR
- ❑ Martinez EC boundary condition is identical for SLR and non-SLR conditions

Apply EC regression equation for 1 foot SLR Scenarios

Method

- ❑ Uniformly increase the tidal stage boundary condition at Martinez by 1 foot
- ❑ Apply the modified G-model to determine base (non-SLR) Martinez EC based on an astronomical tide and NDO
- ❑ Compute Martinez EC for 1-foot SLR from regression relationship correlating base EC and 1-foot SLR EC (Eqn. 5-1)

Characteristics

- ❑ Intrusion of ocean water into the Delta under SLR conditions is considered
- ❑ EC at Martinez for base conditions without SLR must be known or computed in order to apply the regression equation (e.g., modified G-model)
- ❑ Current regression equation can only be applied for 1-foot SLR
- ❑ Represents increase in salt intrusion from the ocean due to SLR
- ❑ Regression relationship was developed for a limited data set during dry conditions

5.7 References

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

26th Annual Progress Report
October 2005

Chapter 6:
Fingerprinting: Clarifications and Recent Applications

Authors: Jamie Anderson and Jim Wilde

6 Fingerprinting: Clarifications and Recent Applications

6.1 Introduction

Within the context of the modeling of the hydrodynamics and water quality of the Sacramento-San Joaquin Delta, *fingerprinting* refers to a methodology for running the Delta Simulation Model II to determine sources of water or constituents at specified locations. The DSM2 fingerprinting methodology is described in detail in Anderson (2002). The two main purposes of this chapter are to clarify the types of fingerprinting and to present recent fingerprinting applications.

6.2 Fingerprinting Overview

Fingerprinting provides an application of DSM2 that can improve understanding of circulation in the Delta by examining sources of water and/or constituents at specified locations. A fingerprinting analysis is analogous to collecting a bucket of water at a given location and determining how much water (or how much of a constituent) in the bucket came from each potential source. To conduct a fingerprinting study, the QUAL module of DSM2 is run with user-defined conservative constituents representing the source waters or source constituent concentrations (see Anderson, 2002 for additional details). For the Sacramento-San Joaquin Delta representation in DSM2, six major sources are typically considered:

<u>Fingerprinting Source Locations</u>

- ❑ Sacramento River at Sacramento
- ❑ San Joaquin River at Vernalis
- ❑ Martinez (ocean/bay water)
- ❑ Eastside streams (Calaveras, Mokelumne, and Cosumnes Rivers)
- ❑ Agricultural return flows
- ❑ Yolo Bypass

Fingerprinting analysis typically is conducted to determine either (a) how much of the water at a specified location and time came from each of the above sources or (b) how much of a constituent (for example, electrical conductivity or dissolved organic carbon) at a given location and time came from each of the above sources. A sample fingerprinting analysis for source water, EC and DOC at Clifton Court Forebay for historical conditions for January–April 2005 is presented in Figure 6.6 in the Recent Applications section of this chapter. The next section of this chapter further describes the types of fingerprinting analysis and provides illustrative examples.

6.3 Clarification on Types of Fingerprinting

Because the term *fingerprinting* can be used in various contexts related to DSM2 studies and analysis, this section aims to clarify what is meant by *fingerprinting* by providing descriptions of the different types of fingerprinting analysis including some illustrative examples.

6.3.1 Volumetric and Constituent Fingerprinting

There are two main types of fingerprinting analysis (Figure 6.1):

- ❑ Volumetric Fingerprinting
- ❑ Constituent Fingerprinting

Volumetric fingerprinting determines the portion of the volume of water contributed from each source at a specified location and time. Volumetric fingerprinting is analogous to collecting a bucket of water at a specified location in the Delta and determining how much of the water came from the Sacramento River, the San Joaquin River, Martinez, agricultural return flows, and other sources.

Constituent fingerprinting determines the portion of a constituent concentration that originates from each source at a specified location and time. Constituent fingerprinting is analogous to collecting a bucket of water at a specified location and time in the Delta and determining how much of the salinity (or other constituent) in the bucket came from the Sacramento River, the San Joaquin River, Martinez, agricultural return flows, and other sources. For the example in Figure 6.1, the majority of the water comes from the Sacramento River. However, Martinez contributes most of the EC.

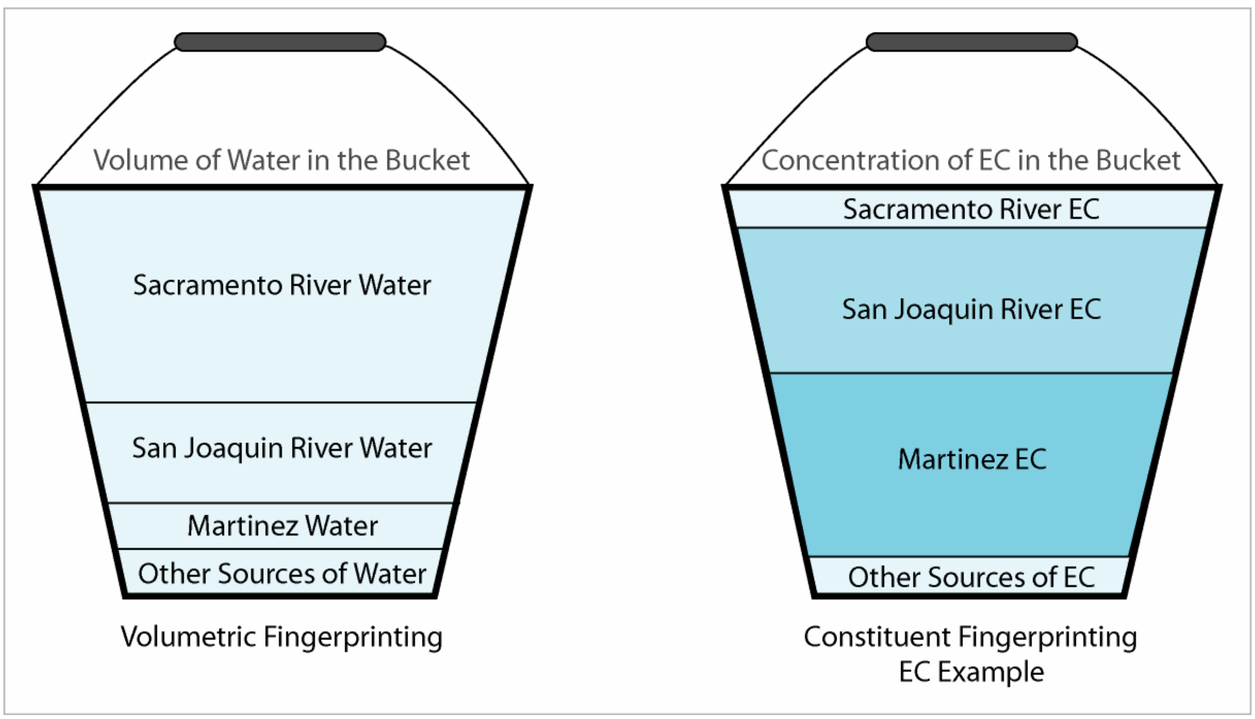

Figure 6.1: Volumetric and Constituent Fingerprinting Conceptualizations.

6.3.2 Timed Fingerprinting

Volumetric or constituent fingerprinting analyses provide information related to the source of the water or constituent. In a typical fingerprinting simulation, the source of the water or constituent is examined, but timing associated with that source is not considered. There are times when it may be of interest to have information related to the timing of the source. For example, after transition periods with large changes in flows or concentrations, it may be of interest to know how much of the water or constituent at a given location originated before or after the transition. A Delta example could be the VAMP (Vernalis Adaptive Management Plan) period from April 15 to May 15 when San Joaquin River flows are increased. To better understand changes in water quality after VAMP, it may be desired to know how much of the water at a given location was contributed before VAMP (prior to April 15), during VAMP (April 15–May 15), or after VAMP (after May 15).

If the timing associated with that source is also of interest, the fingerprinting analysis can be extended to consider both when and where the water or source contribution originated. For example, to better understand changes in water quality after VAMP, it may be desired to know how much of the water at a given location was contributed by the San Joaquin River before, during, and after VAMP compared to the Sacramento River. Similar to the basic fingerprinting analysis, there are two main types of timed fingerprinting analysis (Figure 6.2):

- Volumetric Timed Fingerprinting
- Constituent Timed Fingerprinting

For a timed fingerprint analysis, the source water or source constituent information is tracked by both origin location and timing. A timed fingerprinting analysis is analogous to collecting a bucket of water at a specified location and time and determining how much water (or how much of a constituent) originated from each source from each time interval of interest. For example, how much water in the bucket came from the Sacramento River this month, last month, and two months ago? The user defines the source timing period to be examined, for example, per month, per week, or during another specified time period. To conduct a timed fingerprint in the QUAL module of DSM2, the user specifies a conservative constituent to represent each source at each time interval. Thus a timed fingerprinting analysis is more labor intensive to set up and analyze than a basic fingerprinting analysis. A timed fingerprinting analysis is also more computationally expensive because each source at each analysis interval is represented by a separate conservative constituent.

A timed fingerprinting conceptualization is shown in Figure 6.2 considering two time periods for each source location, T_o and T_o-1. These time periods can represent any two consecutive periods such as this month and last month or this week and last week. The Sacramento River is the main source of water volume, with the majority of the contribution coming from the current time period (T_o) and less of the water originating from the previous time period (T_o-1). The main source of EC is Martinez. Similarly the majority of the EC is contributed during the current time period (T_o) with less EC originating from the previous time period (T_o-1).

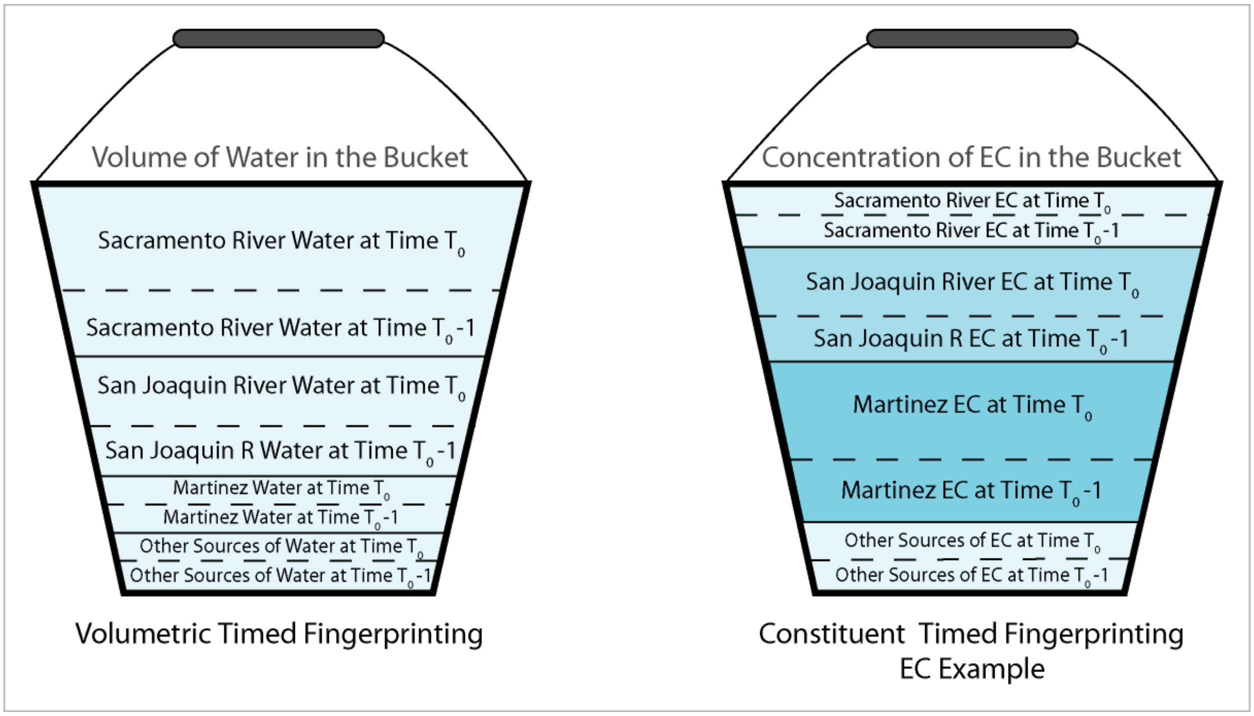

Figure 6.2: Timed Fingerprinting Conceptualizations.

6.3.3 Fingerprinting Example

Fingerprinting analyses for semi-steady state scenarios were conducted to illustrate volumetric and constituent fingerprinting. In a steady state scenario, the Delta inflows and exports do not change over time. These simulations are considered semi-steady state because the stage boundary condition at Martinez varies with time. A time varying tidal boundary condition is necessary at Martinez in order to produce bidirectional tidal flows. A constant stage at Martinez results in unidirectional flows, which are not reflective of Delta hydrodynamics.

Two semi-steady state scenarios were simulated to illustrate how fingerprinting can improve understanding of the effects of system operations on Delta hydrodynamics and water quality.

Semi-Steady State Scenarios

- ❑ Dry spring with the Delta Cross Channel closed
- ❑ Dry spring with the Delta Cross Channel open

For the semi-steady state simulations, the following constant Delta inflows, exports, and EC concentrations representative of drier spring conditions were used (Table 6.1). The Clifton Court Forebay gates were operated to allow inflow into the forebay whenever the water level in the channel was greater than the water level inside the forebay. Because this analysis is for illustrative purposes only, south Delta temporary barriers and minor inflows and exports were not considered. The only difference between the two scenarios is the operation of the Delta Cross Channel gates. The simulations were run for a one-year period to ensure that the effects of assumed initial conditions were removed and that steady state was reached.

Table 6.1: DSM2 Semi-Steady State Scenario Boundary Conditions.

Location	**Boundary Condition Value**	
Delta Inflows	***Flows***	***EC***
Sacramento River	10,000 cfs	175 uS/cm
San Joaquin River	1,000 cfs	500 uS/cm
Delta Exports	***Exports***	***EC***
State Water Project	2,000 cfs	N/A
Central Valley Project	2,000 cfs	N/A
Contra Costa Canal	200 cfs	N/A
Tidal Stage	***Stage***	***EC***
Martinez	Adjusted Astronomical Tide	20,000 uS/cm

To illustrate fingerprinting analyses, three sources were considered for inflows and EC:

Fingerprinting Source Locations

- ❑ Sacramento River
- ❑ San Joaquin River
- ❑ Carquinez Strait at Martinez (ocean/bay water)

In fingerprinting simulations, separate user-defined conservative constituents are defined for each source. For a volumetric fingerprinting simulation, the concentration of each user-defined conservative constituent can be set to a value of 100, so that at any location in the Delta, the value of that constituent represents the percent contribution from that source. For a constituent fingerprinting simulation, each user-defined conservative constituent is set to the same value as the water quality constituent of interest at that source (EC in this example). Values of the user-defined volumetric and constituent fingerprinting conservative constituents are presented in Table 6.2.

Table 6.2: Fingerprinting Boundary Conditions for Semi-Steady State Scenarios.

Location	**Volumetric Fingerprinting Boundary Values**	**Constituent Fingerprinting Boundary Values**
Sacramento River at Sacramento	100	175
San Joaquin River at Vernalis	100	500
Martinez	100	20,000

For each type of fingerprinting, an additional fingerprinting conservative constituent was defined to check for conservation of mass. For volumetric fingerprinting, the mass conservation constituent should have a value of 100 at all locations in the system; and for constituent fingerprinting, the mass conservation constituent should have the value of the water quality constituent being simulated (EC in this example). Thus for these examples, four user-defined conservative constituents (Sacramento River, San Joaquin River, Martinez, and mass conservation check) were defined for volumetric and constituent fingerprinting, resulting in eight total fingerprinting constituents.

For analysis of results, semi-steady state was assumed to be reached when the value of the volumetric mass balance conservative constituent equaled 100 (representing 100% of the flow sources) at all locations. For these scenarios, semi-steady state was reached in approximately 10 months when the Delta Cross Channel gates were closed and 6 months when they were open. Simulation results presented in this chapter are for one year after the start of the simulation to ensure that the simulation had reached semi-steady state and so that the Adjusted Astronomical Tide corresponded to drier spring conditions. Daily average semi-steady state fingerprinting results at the end of a one-year simulation are presented at three Delta urban intakes (Figure 6.3) for the scenarios with the Delta Cross Channel gates closed (Table 6.3 and Figure 6.4) and with the Delta Cross Channel gates open (Table 6.4 and Figure 6.5).

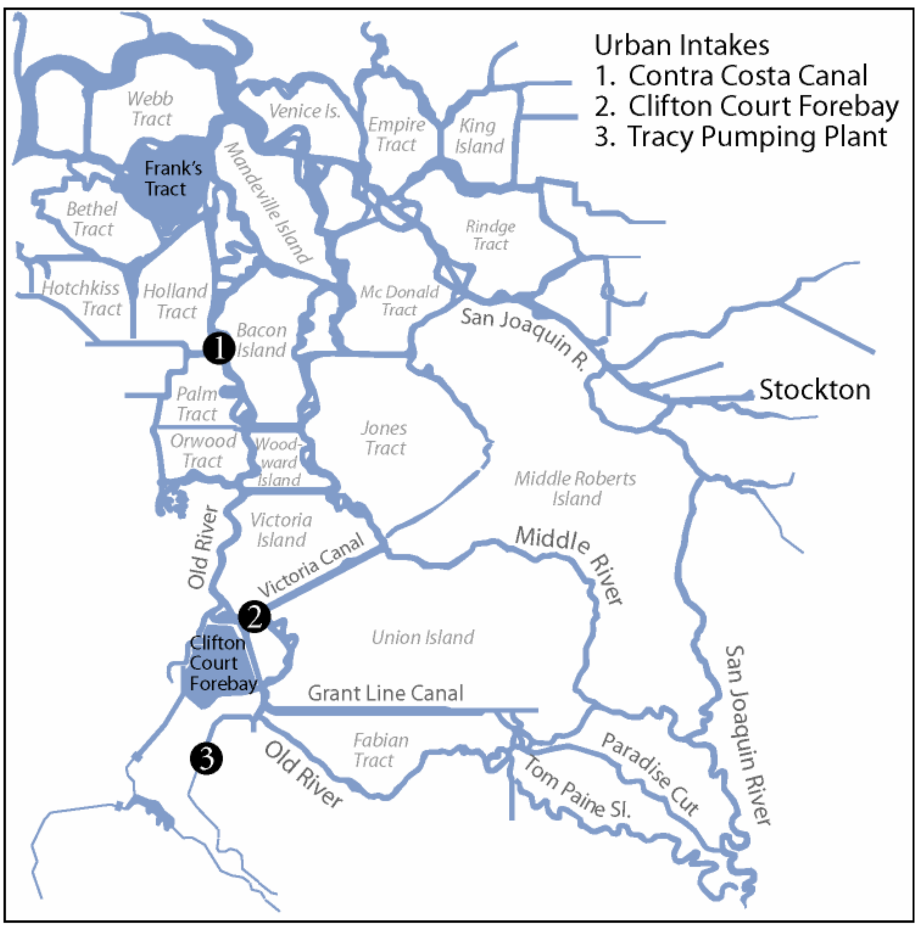

Figure 6.3: Delta Urban Intake Locations.

Table 6.3: Fingerprinting Results at Urban Intakes for a Dry Spring Semi-Steady State Scenario with the Delta Cross Channel Gates Closed.

Location	Volumetric Fingerprinting		Constituent Fingerprinting	
	Flow	% Contribution of Water	Total EC	EC Contribution
Contra Costa Canal	200 cfs	***Total = 99.8%***[1]	468 uS/cm	***Total = 468 uS/cm***
Sacramento River		97.9 %		171 uS/cm (36.6%)
San Joaquin River		0.5 %		2 uS/cm (0.5%)
Martinez		1.5 %		295 uS/cm (62.9%)
Clifton Court Forebay	1736 cfs[2]	***Total = 99.7%***	400 uS/cm	***Total = 400 uS/cm***
Sacramento River		91.8 %		161 uS/cm (40.2%)
San Joaquin River		6.9 %		34 uS/cm (8.6%)
Martinez		1.0 %		205 uS/cm (51.3%)
Tracy Pumping Plant	2000 cfs	***Total = 99.8%***	440 uS/cm	***Total = 440 uS/cm***
Sacramento River		54.6 %		96 uS/cm (21.7%)
San Joaquin River		44.6 %		223 uS/cm (50.7%)
Martinez		0.6 %		121 uS/cm (27.6%)

Table 6.4: Fingerprinting Results at Urban Intakes for a Dry Spring Semi-Steady State Scenario with the Delta Cross Channel Gates Open.

Location	Volumetric Fingerprinting		Constituent Fingerprinting	
	Flow	% Contribution of Water	Total EC	EC Contribution
Contra Costa Canal	200 cfs	***Total = 99.9%***[1]	299 uS/cm	***Total = 299 uS/cm***
Sacramento River		98.8 %		173 uS/cm (57.8%)
San Joaquin River		0.5 %		3 uS/cm (0.9%)
Martinez		0.6 %		124 uS/cm (41.4%)
Clifton Court Forebay	1732 cfs[2]	***Total = 99.9%***	267 uS/cm	***Total = 267 uS/cm***
Sacramento River		92.8 %		162 uS/cm (60.8%)
San Joaquin River		6.8 %		34 uS/cm (12.8%)
Martinez		0.4 %		70 uS/cm (26.4%)
Tracy Pumping Plant	2000 cfs	***Total = 100.0%***	361 uS/cm	***Total = 361 uS/cm***
Sacramento River		54.9 %		96 uS/cm (26.6%)
San Joaquin River		44.8 %		224 uS/cm (62.1%)
Martinez		0.2 %		41 uS/cm (11.3%)

[1] Totals of slightly less than 100% reflect round-off errors.
[2] The target export at Clifton Court Forebay was 2,000 cfs. Because inflows into the forebay are tidal, the daily average inflow may be slightly greater or slightly less than the target. However the long-term average inflow into the forebay equals the target inflow.

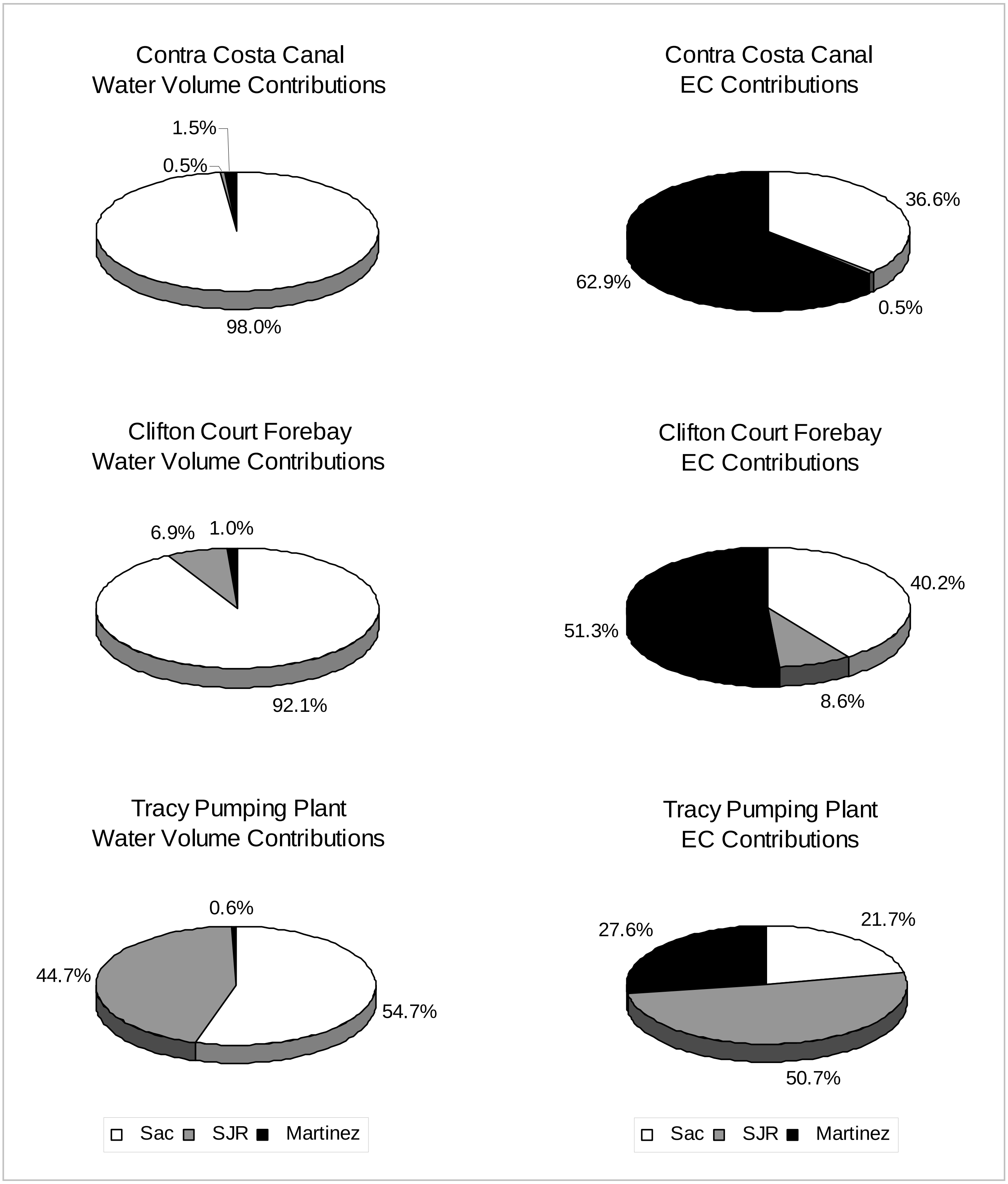

Figure 6.4: Water and EC Contributions at Urban Intakes with Delta Cross Channel Closed for a Semi-Steady State Dry Spring Conditions.

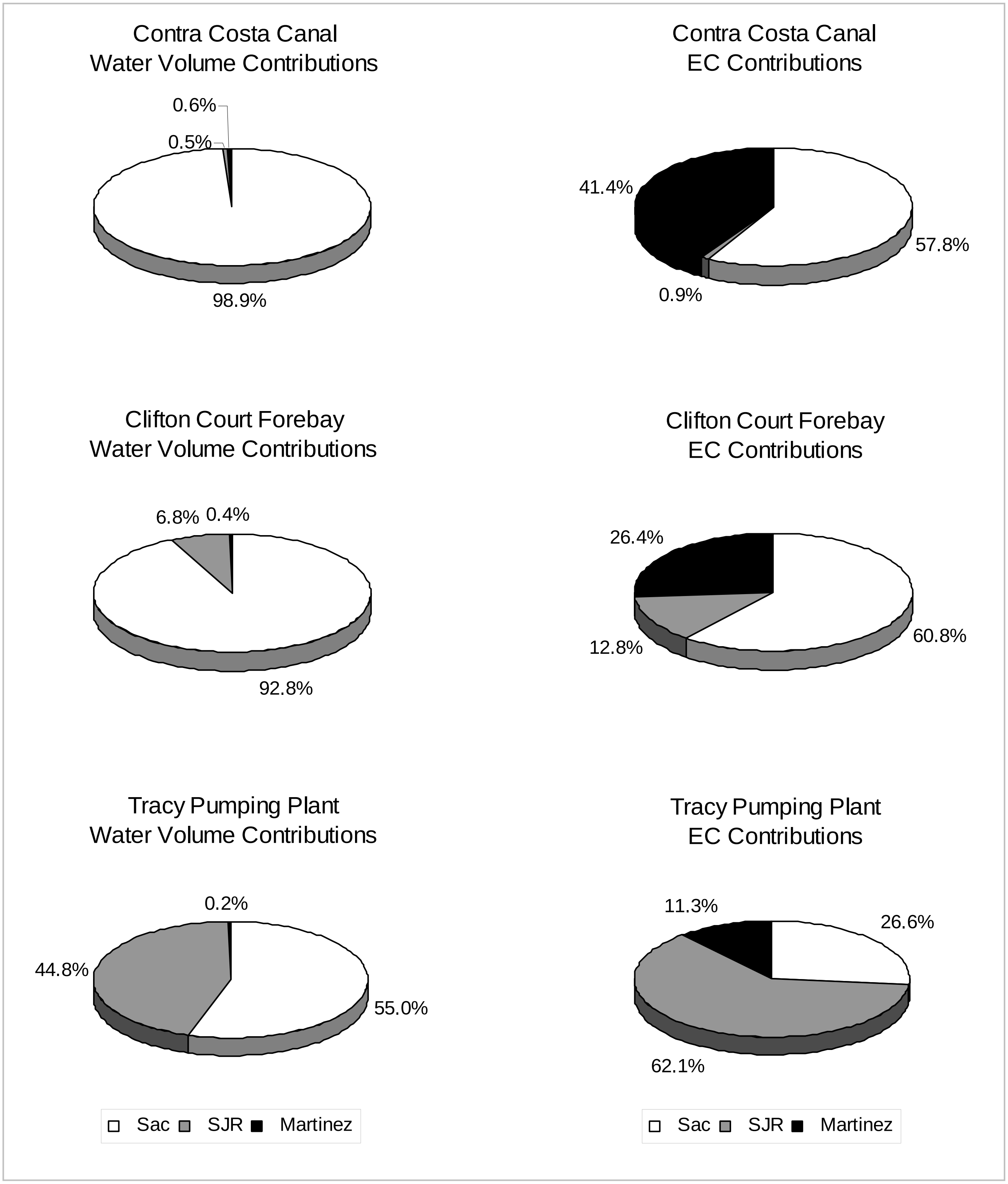

Figure 6.5: Water and EC Contributions at Urban Intakes with Delta Cross Channel Open for a Semi-Steady State Dry Spring Conditions.

In practice, the Delta Cross Channel gates are closed during certain periods in the spring to keep migrating juvenile salmon in the main stem of the Sacramento River and out of the interior Delta. When migrating salmon are not a concern, the Delta Cross Channel gates can be opened to allow relatively fresh Sacramento River water to flow into the interior Delta, thus improving Delta water quality.

An improvement in Delta water quality resulting from opening the Delta Cross Channel gates was shown by the simulation results for dry spring semi-steady state conditions (Table 6.3 and Table 6.4, Figure 6.4 and Figure 6.5). At the urban intakes, opening the Delta Cross Channel gates reduced EC concentrations by approximately 35% at Contra Costa Canal and Clifton Court Forebay and by nearly 20% at Tracy Pumping Plant. Fingerprinting simulation results can be used to gain further insight into how opening the Delta Cross Channel gates reduced EC concentrations at the urban intakes.

Effects of Delta Cross Channel operations on source contributions of water and EC at three urban intakes were examined using volumetric and constituent fingerprinting. For the dry spring conditions, volumetric fingerprinting results show that the Sacramento River was the major source of water at the three urban intakes regardless of the Delta Cross Channel gate position. The San Joaquin River was a significant source of water at the Tracy Pumping Plant, but provided only minor contributions of water at the other two urban intakes.

The constituent fingerprinting results illustrate that Martinez and the San Joaquin River provided the majority of the EC at all three urban intakes. For example, at Contra Costa Canal, Martinez provided only 1.5% of the flow when the Delta Cross Channel gates were closed (Table 6.3 and Figure 6.4). However, because of its high salinity, Martinez provided almost 63% of the EC. Opening the Delta Cross Channel gates resulted in an increase in flow from the Sacramento River of about 1%. Although the increase in freshwater source was relatively small, the corresponding 1% reduction in water from the high salinity source from Martinez reduced the EC contribution from Martinez from 63% to 41% (Table 6.4 and Figure 6.5).

The fingerprinting results can also provide insight into Delta dynamics that cannot be deduced from flow and EC simulations alone. For example, for the scenario with the Delta Cross Channel gates closed (Table 6.3 and Figure 6.4), the EC at Clifton Court Forebay and Tracy Pumping plant were similar (400 uS/cm and 440 uS/cm respectively). Although the EC concentrations were similar, the major source of the EC was different at each intake. For Clifton Court Forebay, the majority of the EC came from Martinez (~51%) and the Sacramento River (~40%). However, for the Tracy Pumping Plant, about half of the EC came from the San Joaquin River (~50%) with the Sacramento River and Martinez providing about a quarter of the EC each (~22% and 28% respectively).

6.4 Recent Applications

Recent applications of DSM2 fingerprinting by the Delta Modeling section fall into two main categories: (1) Understanding historical Delta conditions and (2) Understanding hypothetical Delta conditions for planning studies. The following recent fingerprinting applications are presented in this section:

Understanding Historical Delta Conditions

- ❑ Fingerprinting Reports for MWQI Real Time Data Forecasting Reports
- ❑ Fingerprint of the San Joaquin River at Vernalis
- ❑ Using DSM2 Fingerprints to Check Carbon Dating Studies

Understanding Hypothetical Delta Conditions for Planning Studies

- ❑ Improve Understanding of Delta Flows and Water Quality for SDIP Studies
- ❑ Using Volumetric Fingerprints to Develop DOC Constraints in CALSIM

6.4.1 Fingerprinting Reports for MWQI Real Time Data Forecasting Reports

Delta Modeling Section staff have been conducting DSM2 fingerprinting studies in support of the California Department of Water Resource's Municipal Water Quality Investigations Program's (MWQI) weekly Real Time Data Forecasting (RTDF) reports. The RTDF report conveys the current conditions of the Delta and provides the best estimates for future conditions in the short term, about two weeks into the future.

Some of the parameters included in the description of current conditions and in the forecasts included in the RTDF are EC and dissolved organic carbon (DOC) at Clifton Court Forebay. In order to better understand the historical conditions upon which those forecasts are based, the following fingerprinting studies are often conducted using a DSM2 simulation of historical conditions:

- ❑ Volumetric fingerprinting for source water
- ❑ Constituent fingerprinting for electro conductivity (EC)
- ❑ Constituent fingerprinting for dissolved organic carbon (DOC)

A sample fingerprinting report for historical percent source water, EC and DOC at Clifton Court Forebay from the May 10, 2005 RTDF report is shown in Figure 6.6 (DWR, 2005). The volumetric fingerprint indicates the historical source contributions of water in Clifton Court Forebay. For example, Figure 6.6 shows the shifting of the major water source from the Sacramento River in January 2005 to the San Joaquin River in April 2005. The individual sources of historical EC and DOC are shown in the constituent fingerprints. The total concentration of historical EC or DOC is indicated by the solid black line at the top of the figure and equals the sum of the constituent contributions from each source. For example, Figure 6.6 shows that by April 2005, the San Joaquin River was the major source of both EC and DOC in the water at Clifton Court. The drop in EC concentration in April 2005 (Figure 6.6) can be further explained by observing that during this time period San Joaquin River flows were relatively high and had relatively low EC concentrations. Such combining of fingerprinting results with knowledge of flows and exports in the system can further enhance understanding of how Delta conditions and operations affect export water quality.

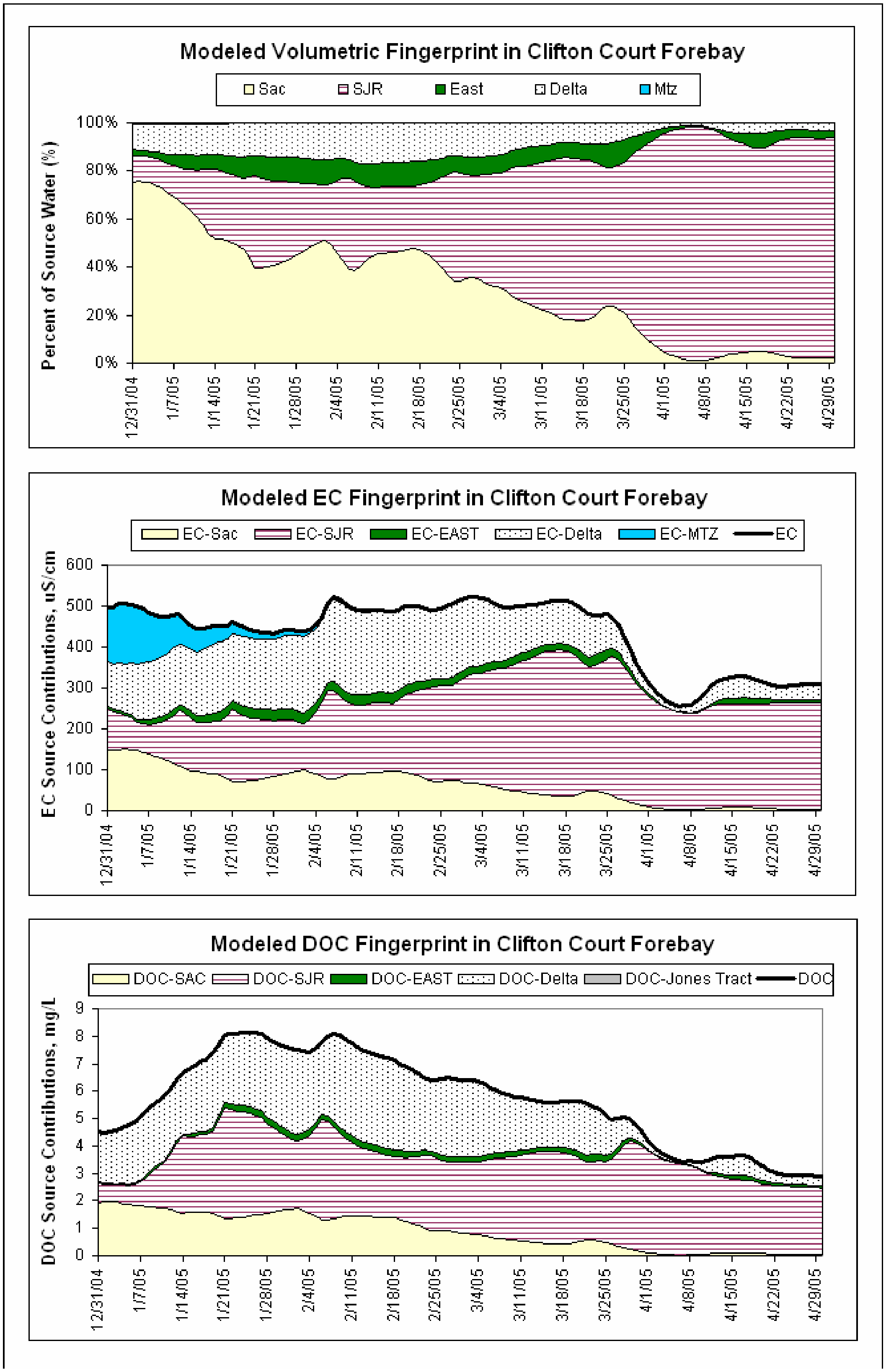

Figure 6.6: Fingerprinting Results for MWQI Real Time Data Forecasting Report May 2005.

6.4.2 Fingerprint of the San Joaquin River at Vernalis

Fingerprinting has been used to better understand how DSM2 with the San Joaquin River extension up to Bear Creek (DSM2-SJR) models flow and salinity in the San Joaquin River at Vernalis (Wilde and Suits, 2004). The major inflows to the reach of the San Joaquin River from Bear Creek to Vernalis are eastside tributaries (the Stanislaus, Tuolumne, and Merced rivers), westside creeks and sloughs (Salt and Mud sloughs, Orestimba, Del Puerto, and Hospital/Ingram creeks), unmonitored yet significant sources such as agricultural drainage, groundwater, and tile drains, as well as the additional water (add-water) needed to force a water balance during calibration as per Pate (2001).

Fingerprinting was used to address such questions as:

- ❑ How much of the Vernalis flow at a given time is from specific tributaries?
- ❑ At Vernalis how do the contributing flows vary seasonally?
- ❑ What are the major sources of salt and how do these vary with time?
- ❑ Which sources of water and salts in the system need better understanding in order to accurately simulate flow and salinity at Vernalis?

As shown in the historical daily volumetric fingerprint values in Figure 6.7, the eastside streams are the dominant source of water at Vernalis (35%-90%). Add-water, assumed a constant rate of 350 cfs all year (Pate, 2001), can also be a significant contributor, particularly in the drier years from 1990 to 1993. Averaging these values by month over the simulation period reveals the source water seasonal variation by volumetric percent (Figure 6.8). The eastside tributaries' relative contribution to total flow in the summer is only marginally less than in the winter due to the system's highly managed and substantial reservoir storage capacity. The unmonitored sources of return flow add more to the system in the summer than in the winter, and the westside creeks and sloughs contribute more in the winter and early spring.

The daily salinity fingerprint in Figure 6.9 shows a highly seasonal fluctuation in source contribution to salinity at Vernalis. Figure 6.9 also reveals the important dry period contribution to salinity at Vernalis of the add-water which is assumed to have an EC of twice that for Orestemba Creek as according to Pate (2001). From 1990 through 1993 add-water contributes 30%-60% of the San Joaquin River salt load at Vernalis. For monthly averaged values from 1990 to 1999, the add-water salt load contribution is 20%-40% (Figure 6.10). This large contribution of salt by unknown water source, as revealed by fingerprinting, is guiding the review of the assumptions in DSM2-SJR modeling of historical conditions and helps highlight the significance of the unknown sources of flow and salt to current modeling capabilities.

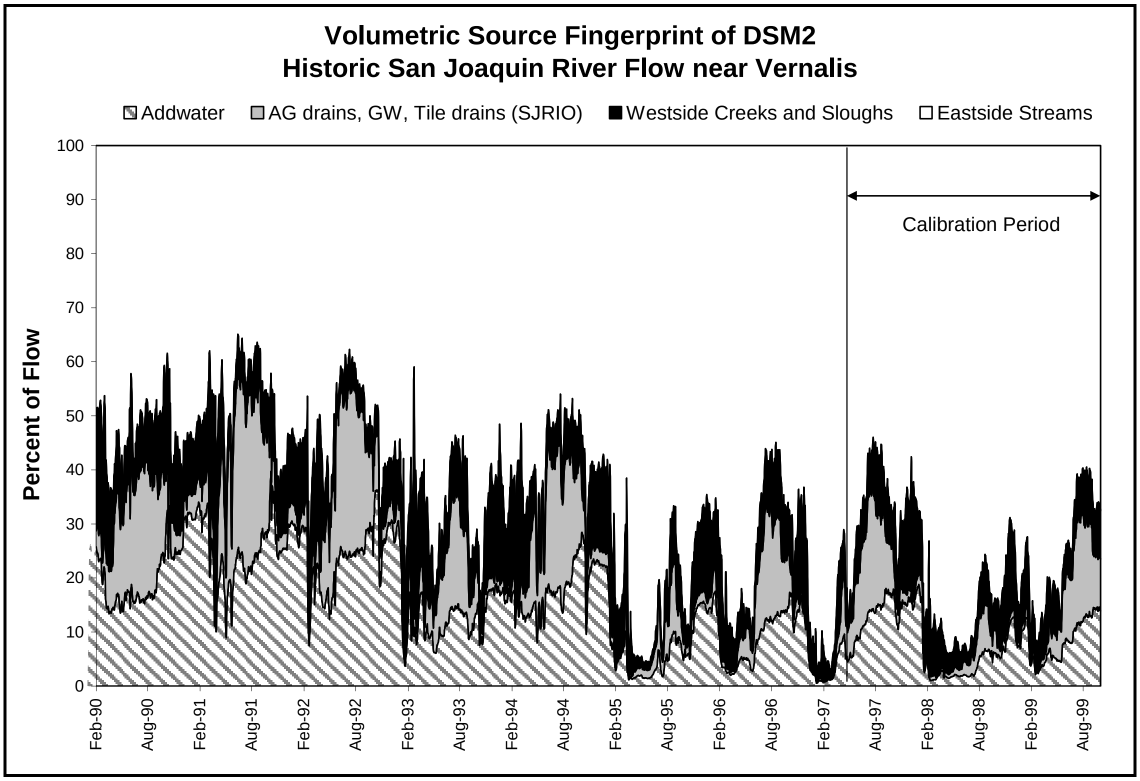

Figure 6.7: DSM2-SJR Generated Volumetric Fingerprint at Vernalis Indicating the Relative Flow Contribution from Grouped Sources.

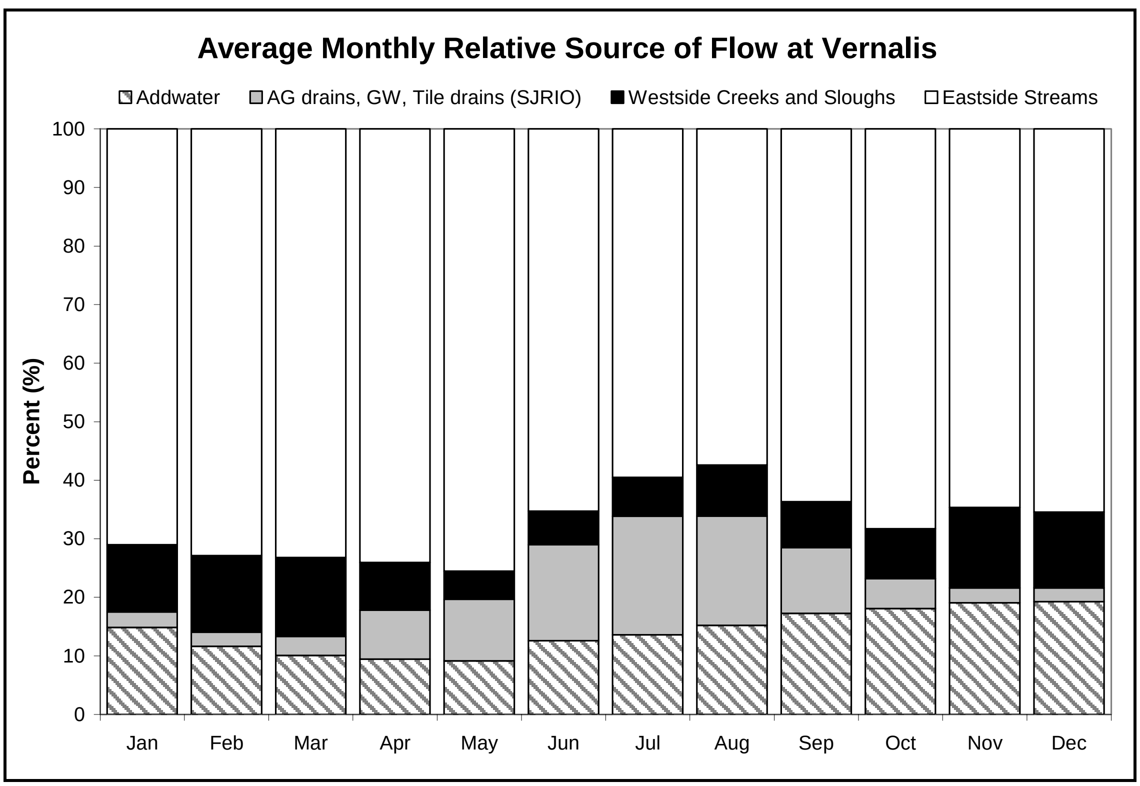

Figure 6.8: DSM2-SJR Generated Average Monthly Volumetric Source Contribution at Vernalis over the January 1990 – September 1999 Simulation Period.

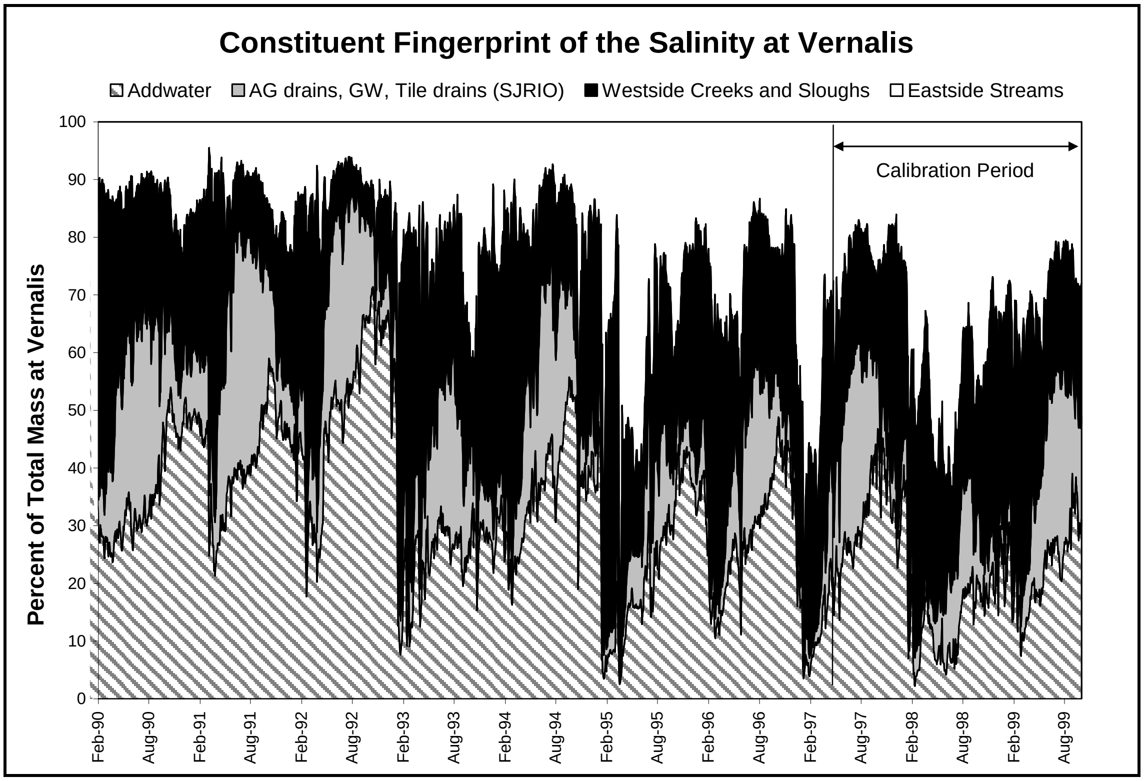

Figure 6.9: DSM2-SJR Generated Constituent Fingerprint at Vernalis Indicating the Relative Load Contribution from Grouped Sources.

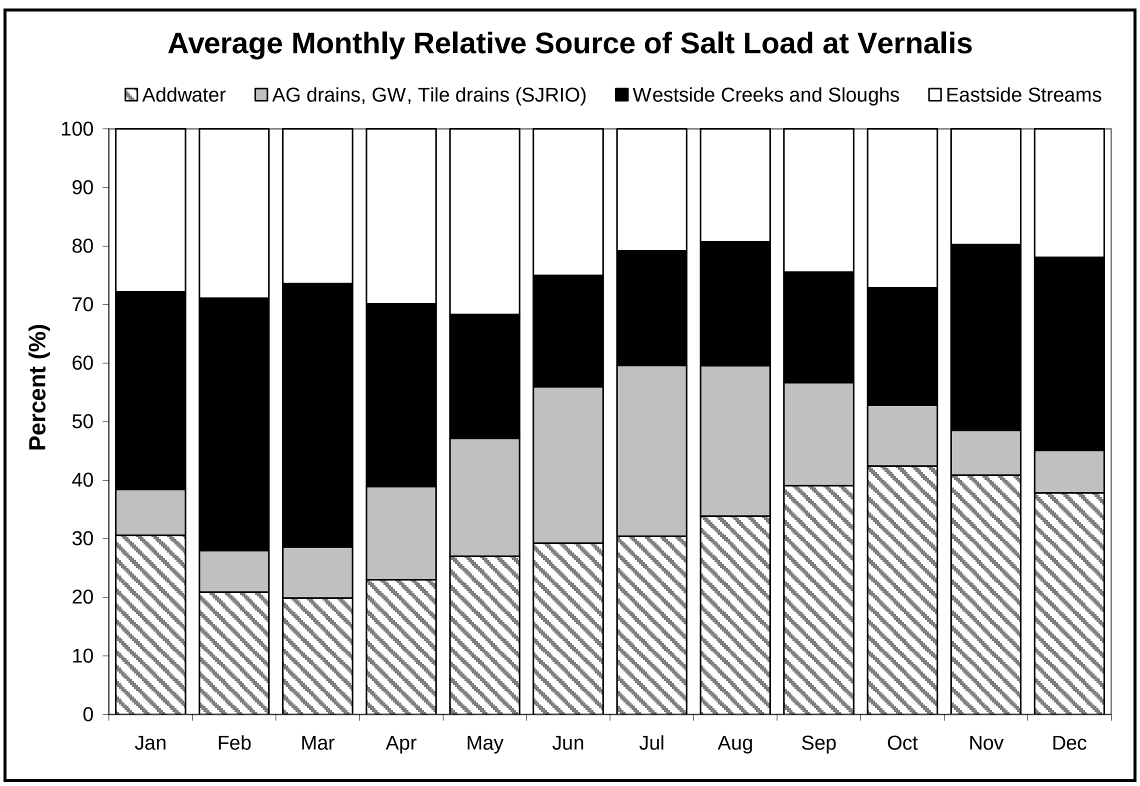

Figure 6.10: DSM2-SJR Generated Average Monthly Percent Contribution of Salinity at Vernalis over the January 1990 – September 1999 Simulation Period.

6.4.3 Using DSM2 Fingerprints to Check Carbon Dating Studies

Coupling the radiocarbon fingerprint for Delta peat-derived carbon with DSM2 volumetric fingerprints has allowed DWR, Lawrence Livermore National Laboratory, and University of Florida researchers to model both the quantity and quality of dissolved organic matter (DOM) exported from the Sacramento – San Joaquin Delta to the California State Water Project (DiGiorgio et al., 2004). The source of water and DOM at Banks Pumping Plant simulated in DSM2 was compared with the radiocarbon content of DOM samples to help validate changes in DOM as it moved through the Delta. Preliminary results from the radiocarbon study indicate that the DOM pool is buffered in terms of size, but it is in dynamic flux, turning over fairly rapidly as it is transported through the river system.

6.4.4 Improve Understanding of Delta Flows and Water Quality for SDIP Studies

Fingerprinting analyses have been used to improve impacts assessments of changes in Delta water quality as a result of implementation of elements of the South Delta Improvements Program (SDIP). This section briefly reviews two such fingerprinting applications:

- Investigate contributions of agricultural drainage to South Delta flows and EC (Nader and Shrestha, 2005)
- Improve understanding of potential impacts of proposed permanent barrier operations on Delta water quality (Anderson, 2005)

These fingerprinting applications are described in more detail below. Because the focus of this paper is to describe various fingerprinting applications, the study questions and approach are summarized. However, the results from the studies are not presented.

Agricultural Drainage Impacts on Delta EC

One set of fingerprinting studies conducted for SDIP examined contributions of agricultural drainage to South Delta flows and EC in Middle and Old rivers (Nader and Shrestha, 2005). Both volumetric and constituent fingerprinting analyses were conducted. Two main issues were investigated: (1) high agricultural drainage contributions when flows were nearly stagnant, and (2) sensitivity of Brandt Bridge EC to potential errors in agricultural drainage EC concentrations.

Volumetric fingerprinting analyses indicated that the highest agricultural drainage contributions to flows in the South Delta occurred at Old River at Tracy Road and Middle River at Mowery Bridge. Low net flows at these locations resulted in higher flow contributions from agricultural drainage.

Additional fingerprinting analyses determined the contribution of Brandt Bridge EC from agricultural drainage. These results were used to conduct a sensitivity analysis of how potential errors in estimating agricultural drainage EC may affect the estimate of Brandt Bridge EC.

Barrier Operation Impacts on Water Quality

Another fingerprinting analysis was conducted for SDIP to improve understanding of differences in modeled Delta water quality for various operational scenarios of planned tidal barriers (Anderson, 2005). Water quality simulations using DSM2-QUAL quantify differences in water quality constituent concentrations between alternatives. Because the results are time series of concentrations at a location, there is no direct indication of why the concentrations differed between alternatives. Fingerprinting analysis can provide additional understanding by indicating how the mix of water from various sources changes for each scenario. For example, a fingerprinting analysis may indicate that an improvement in water quality at a certain location is due to an increased flow contribution at that location from a better quality source or a reduced flow contribution from a high concentration source.

For SDIP impacts assessments, several DSM2 hydrodynamic and water quality simulations were conducted for various operational scenarios for South Delta fish and agricultural barriers (for example, no barriers, temporary barriers, proposed permanent barriers). For certain scenarios, reasons for changes in water quality were not readily evident, thus volumetric fingerprinting analyses were conducted to directly view how the various operational scenarios affected the source flow contributions at selected locations. For example, fingerprinting results indicated that an improvement in EC at Old River at Bacon Island for one scenario was due to a slight decrease in the source contribution from Martinez. Although the reduction in volume contributed by Martinez was small, the high source EC concentration for Martinez resulted in a noticeable reduction in EC at Old River at Bacon Island.

6.4.5 Using Volumetric Fingerprints to Develop DOC Constraints in CalSim

Although DWR’s statewide operations model (CalSim) uses an Artificial Neural Network (ANN) to estimate salinity in the Delta, CalSim does not have a method to predict DOC. Special flow-based DOC constraints were necessary for the CalSim and DSM2 In-Delta Storage studies in order to meet the specific DOC objectives that have been placed on the proposed IDS project. Although earlier IDS studies made use of DSM2 Particle Tracking Model island particle fate – flow relationships, the PTM-based approach was limited. Instead, new CalSim DOC constraints were developed by using a volumetric fingerprint at the urban drinking water intakes to establish a relationship between the volume of IDS releases and various flow parameters (Mierzwa and Wilde, 2004). These volumetric fingerprinting-based CalSim DOC constraints have been used in a number of joint CalSim and DSM2 IDS studies.

6.5 Summary

Volumetric, concentration and timed fingerprinting analyses provide insightful tools for improving understanding of how varying inflows with varying constituent concentrations affect water quality in the Delta. This paper describes the types of fingerprinting analysis and presents recent fingerprinting applications.

6.6 References

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Acronyms and Abbreviations

1D – 1-dimensional
2D – 2-dimensional
3D – 3-dimensional
ATT – Adjusted Astronomical Tide
ANN – Artificial Neural Network
BOD – Biochemical Oxygen Demand
BBID – Byron Bethany Irrigation District
CalSim – California Water Resources Simulation Model
CalSim II – California Water Resources Simulation Model II
CCF – Clifton Court Forebay
CCWD – Contra Costa Water District
CDEC – California Data Exchange Center
CDWR – see DWR
CPU – Central Processor Unit
CSDP – Cross Section Development Program
CVP – Central Valley Project (also Tracy Pumping Plant)
cfs – cubic feet per second
DAYFLOW – computer program used to calculate Delta boundary hydrology
DCC – Delta Cross Channel
DFD – DWR Delta Field Division
DICU – Delta Island Consumptive Use Model
DMC – Delta Mendota Canal
DO – Dissolved Oxygen
DOC – Dissolved Organic Carbon
DOM – Dissolved Organic Matter
DSM2 – Delta Simulation Model 2
DSM2-SJR – DSM2 San Joaquin River Extension
DWR – California Department of Water Resources
DWSC – San Joaquin River Stockton Deep Water Ship Channel
EC – electrical conductivity
EIR/EIS -- Environmental Impact Report / Environmental Impact Statement
GIS – Geographic Information System
GLC – Grant Line Canal
HYDRO – DSM2 Hydrodynamics Model
IDS – In-Delta Storage
IEP – Interagency Ecological Program
ISI – Integrated Storage Investigation (part of DWR)
LLNL – Lawrence Livermore National Laboratories
LVR – Los Vaqueros Reservoir intake
MSL – mean sea level
MWD – Metropolitan Water District of Southern California
MWQI – Municipal Water Quality Investigations
NAVD88 – North American Vertical Datum of 1998
NDO – Net Delta Outflow
NGVD – National Geodetic Vertical Datum
NOAA – National Oceanic and Atmospheric Administration
O&M – DWR Operations and Maintenance
OWQ – DWR Division of Environmental Service’s Office of Water Quality
PDT – Pacific Daylight-saving Time
PST – Pacific Standard Time
PTM – DSM2 Particle Tracking Model
PWT – DSM2 Project Work Team
QUAL – DSM2 Water Quality Model

QUAL2E – Enhanced Stream Water Quality Model

RMA – Resource Management Associates

RMA2 – multi-dimensional hydrodynamic finite element model

RMA11 – multi-dimensional water quality finite element model

RMID015 – Middle River at Santa Fe Cut

RMID027 – Middle River near Tracy Blvd.

ROLD024 – Old River at Rock Slough or Old River at Bacon Island

ROLD034 – Old River at CCWD Los Vaqueros Intake

RS – Rock Slough intake

RTDF – Real Time Data Forecasting

RWCF – City of Stockton's Regional Wastewater Control Facility

SDIP – South Delta Improvement Program

SJR – San Joaquin River

SLR – Sea Level Rise

SQL – Structured Query Language

SWP – State Water Project

taf – thousand acre-feet

TDS – Total Dissolved Solids

TMDL – Total Maximum Daily Load

USBR – U.S. Bureau of Reclamation

USGS – U.S. Geological Survey

UVM – Ultrasonic Velocity Meter

VAMP – Vernalis Adaptive Management Plan

WRESTL – programming language used in CALSIM