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

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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.

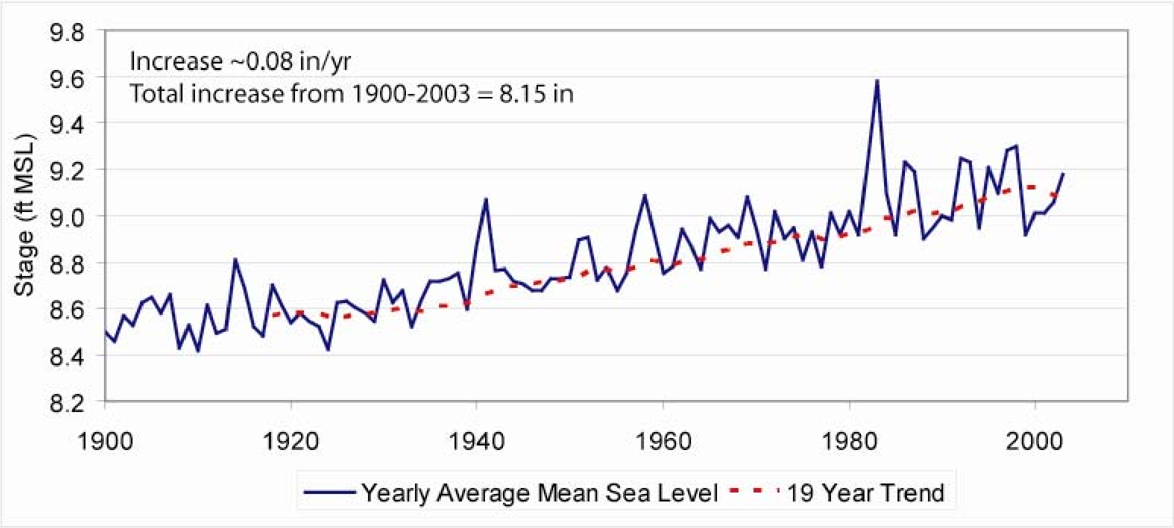

Figure 5.1: Historical Annual Mean Sea Level at Golden Gate, 1900–2003.
(Source: Maury Roos, DWR State Hydrologist).

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.

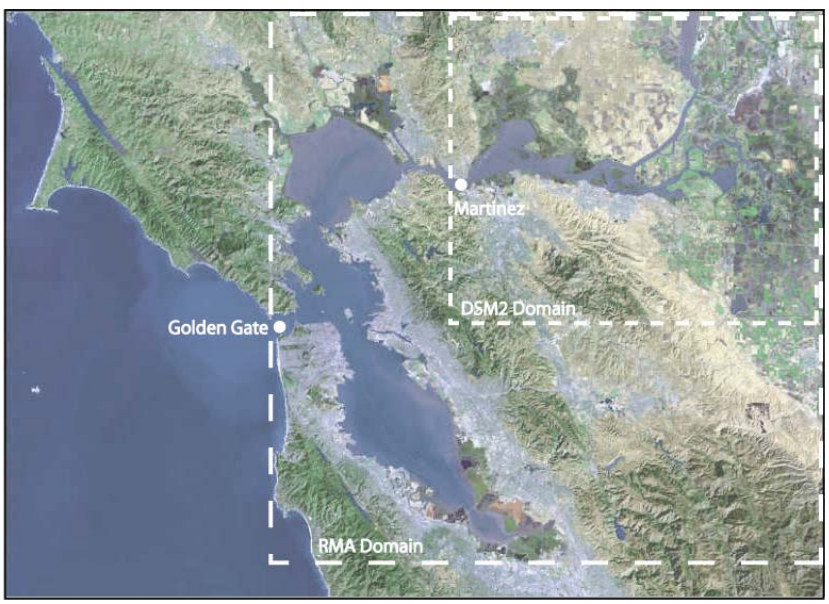

Figure 5.2: Map of San Francisco Bay and the Delta with RMA and DSM2 Model Boundaries. (Satellite image from US Geological Survey).

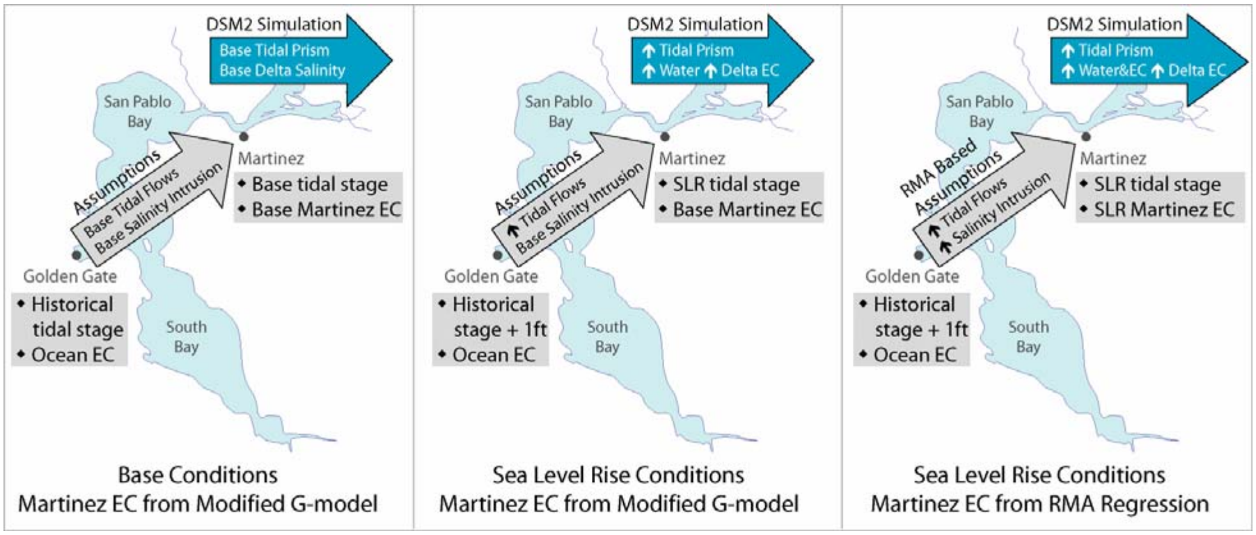

Figure 5.3: Modeling Methods for Simulating Sea Level Rise in the Delta.

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.

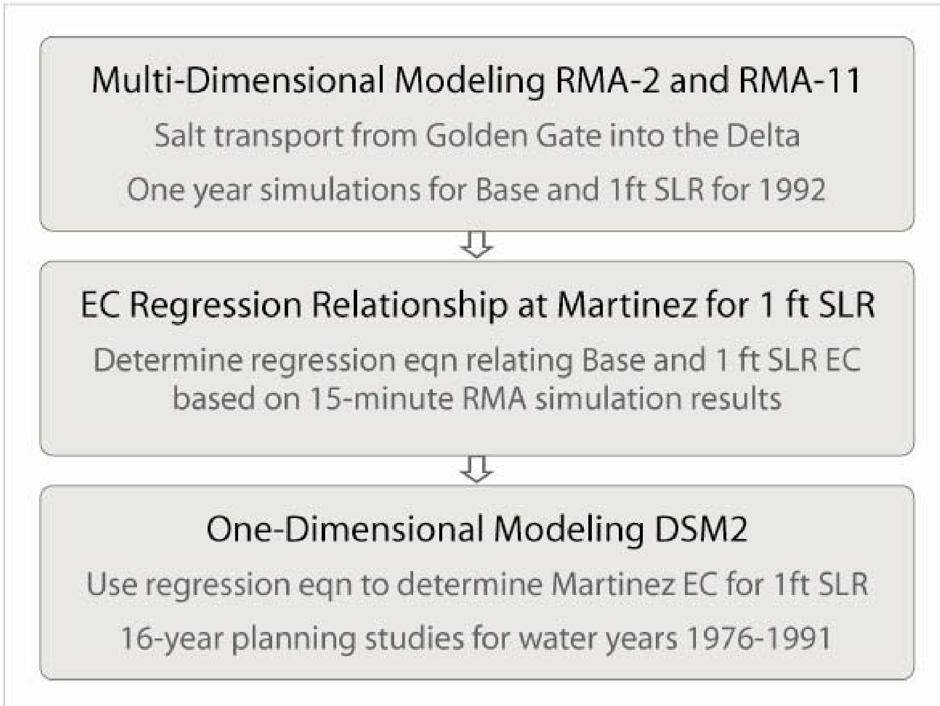

Figure 5.4: Multi-Dimensional Modeling Methodology for Simulated SLR in the Delta.

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.

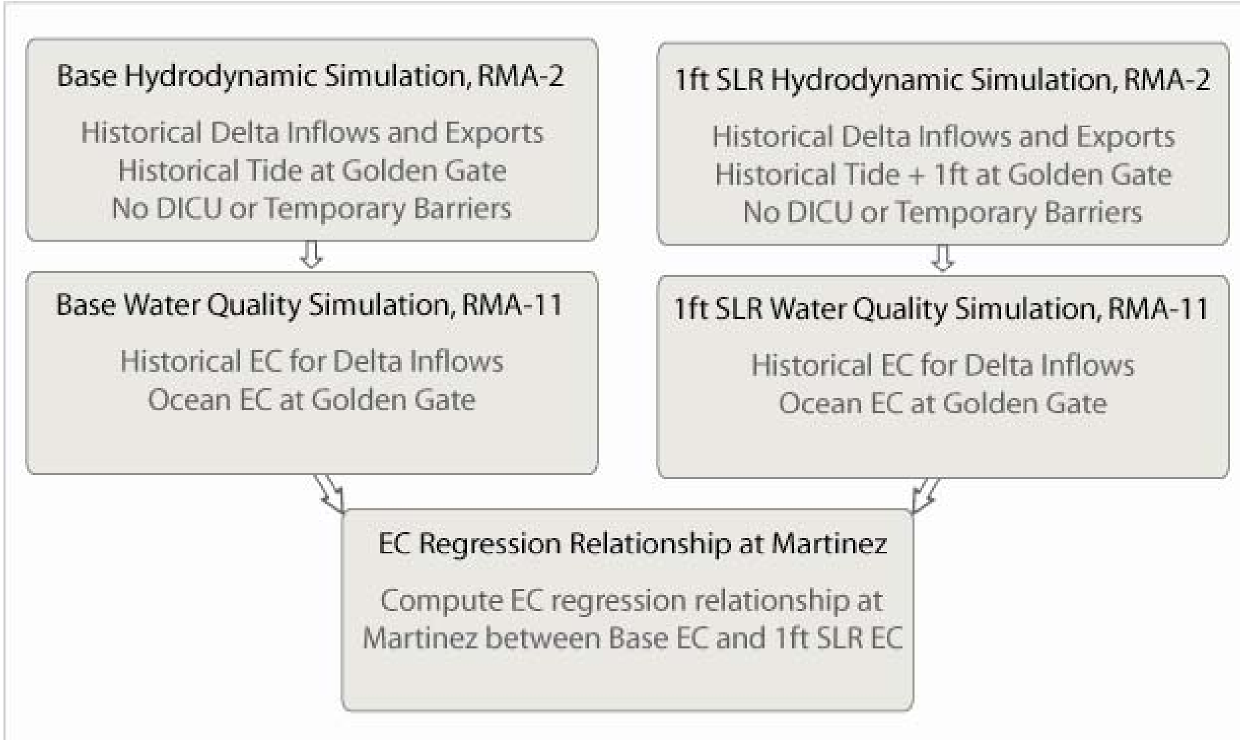

Figure 5.5: Multi-Dimensional RMA Modeling to Develop 1-foot SLR EC Relationship at Martinez.

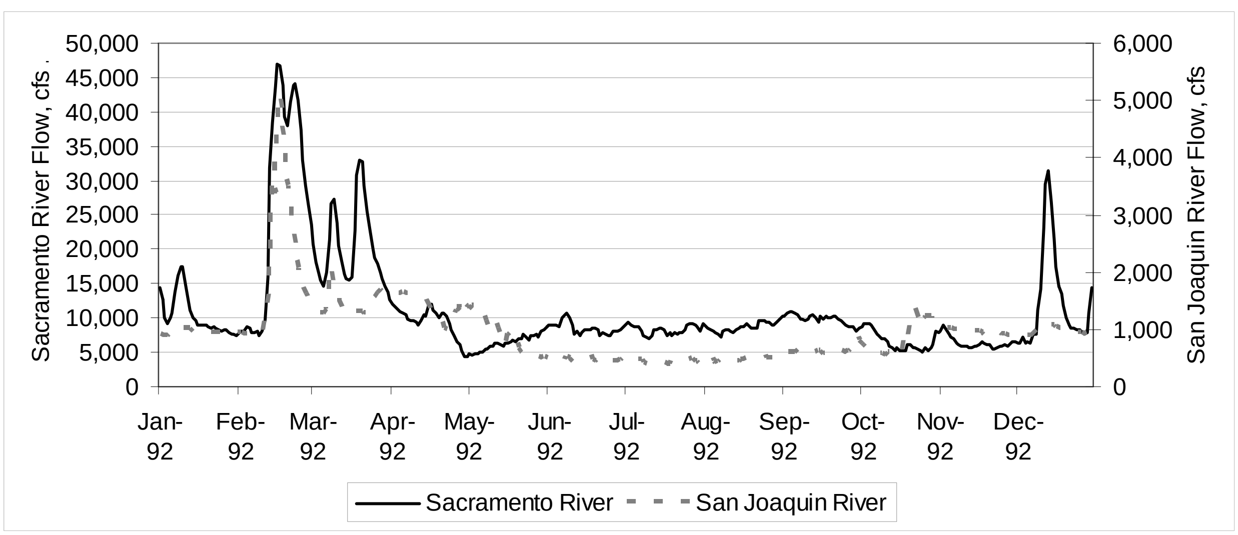

Figure 5.6: Sacramento and San Joaquin River Inflows for 1992.

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.

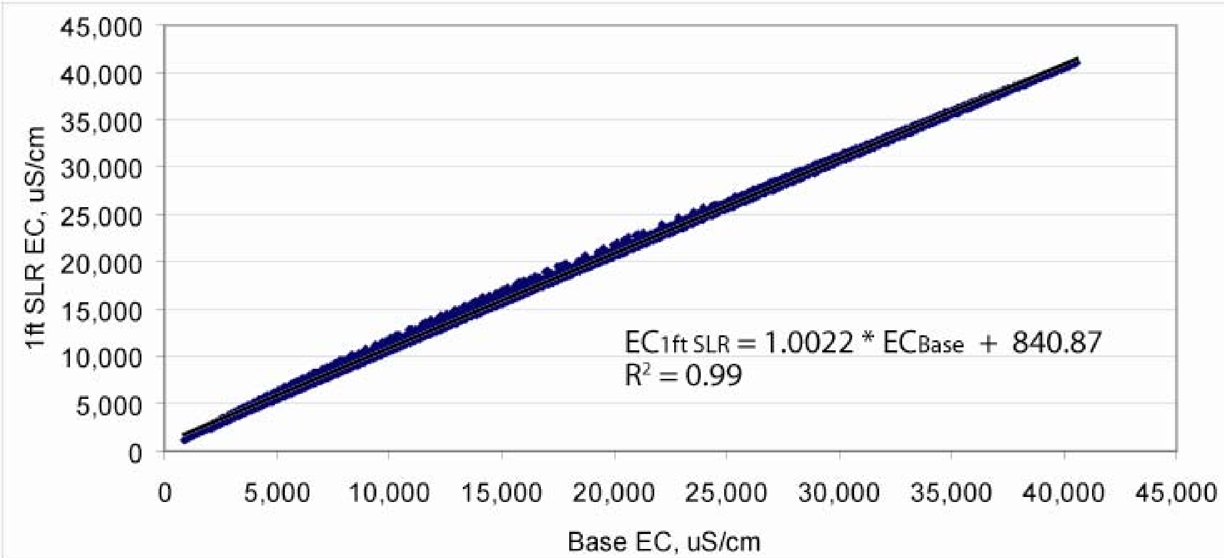

Figure 5.7: Regression Relationship for EC at Martinez for 1-foot Sea Level Rise.

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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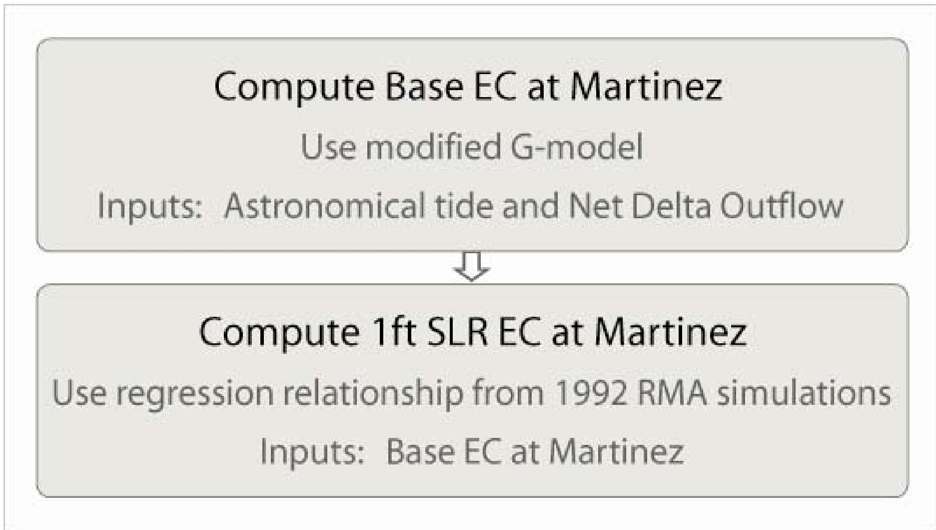

Figure 5.8: Determining Martinez EC for 1-foot SLR from a Regression Equation.

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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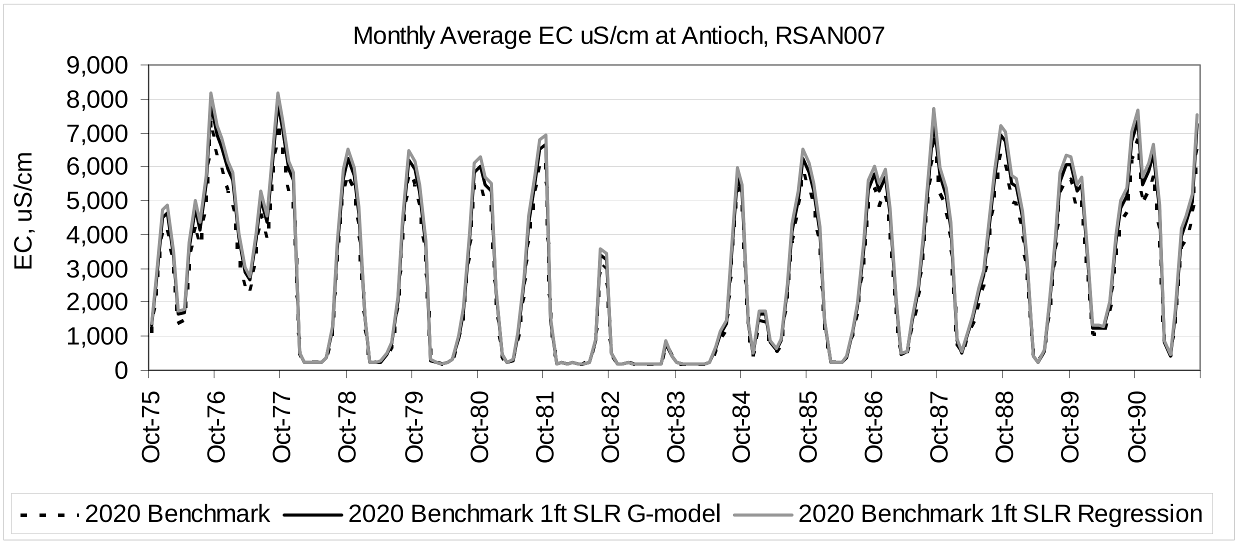

Figure 5.9: Monthly Average Simulated EC at Antioch for 1-foot SLR Scenarios.

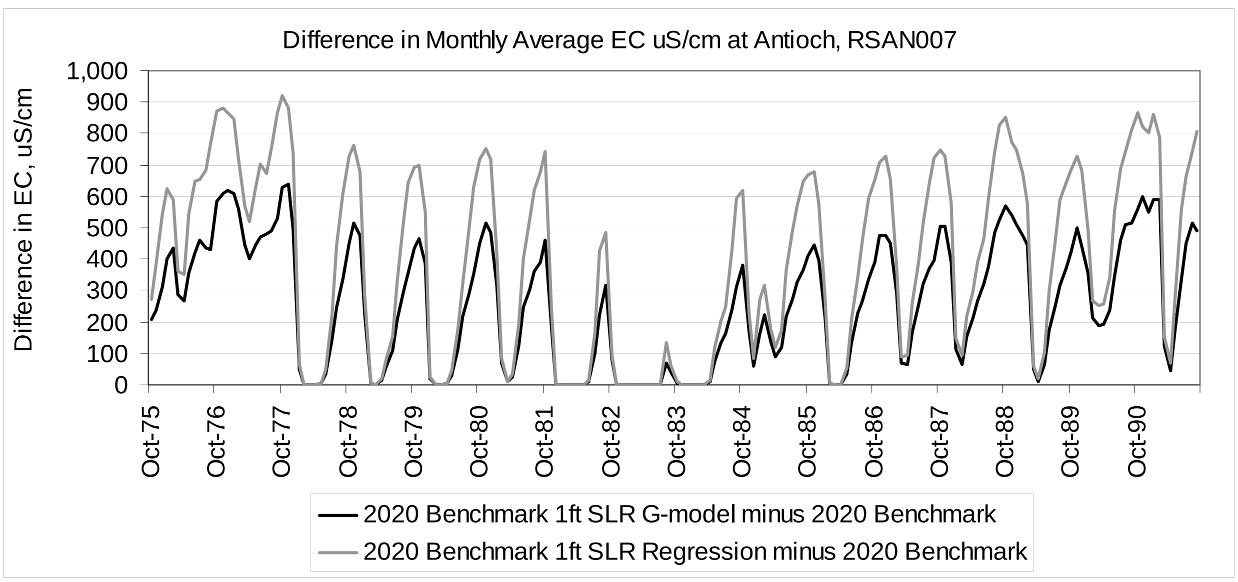

Figure 5.10: Difference in Monthly Average Simulated EC at Antioch for 1-foot SLR Scenarios.

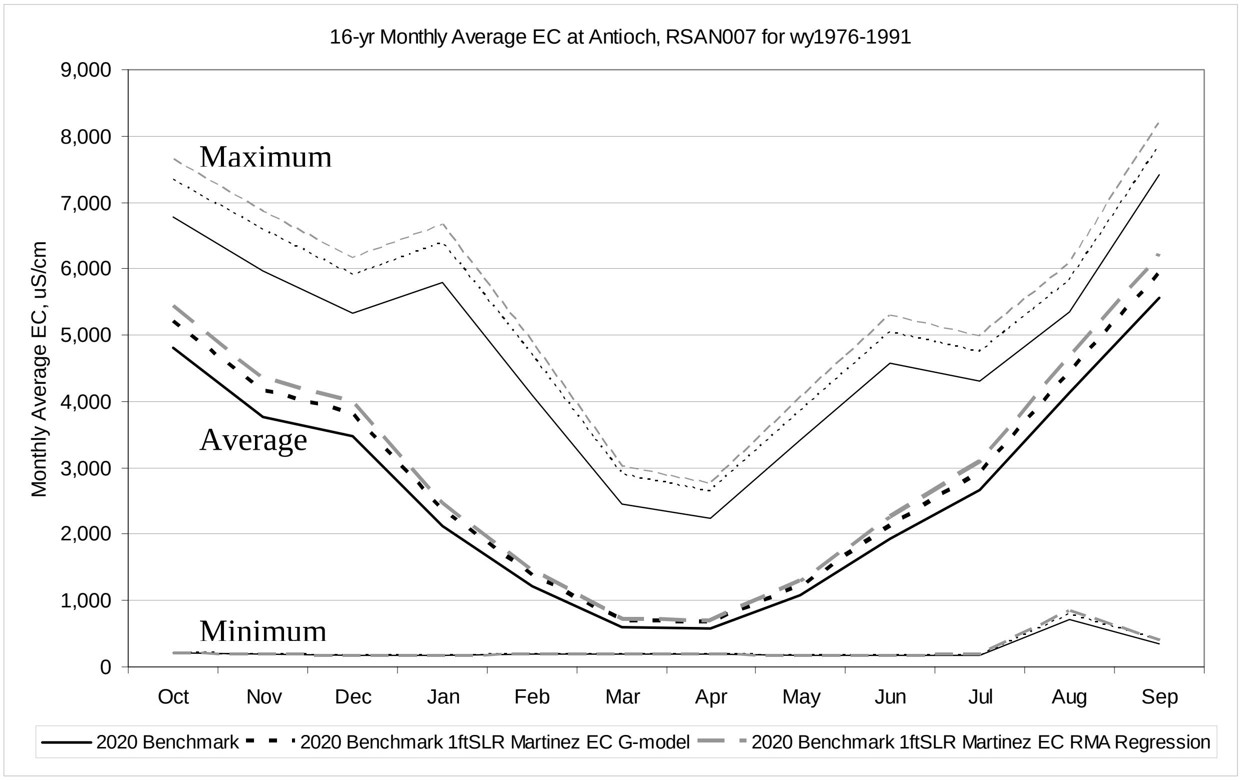

Figure 5.11: 16-Year Monthly Average Simulated EC at Antioch for 1-foot SLR Scenarios.

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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