## Attachment 3: DSM2 Sea Level Rise Corroboration

# 5.B.A.3 Appendix 5B - Attachment 3: DSM2 Sea Level Rise Corroboration

## 5.B.A.3.1 Introduction

In the analysis of the CWF Proposed Action (PA), sea level rise is an integral part of the physical modeling to capture the effects. In the process of preparing Delta Simulation Model (DSM2) for evaluating the CWF alternatives, the simulation of sea level rise in DSM2 is corroborated using the modeling results from higher dimensional models of the California Bay-Delta. This memorandum provides a brief description of the purpose, methodology and the results of this process.

## 5.B.A.3.2 Purpose of Corroboration

CWF NAA and PA scenarios evaluation requires long-term analysis of hydrodynamics and water quality in the Delta resulting from the proposed physical and operational changes. DSM2 is an appropriate model for this type of analysis. It has been successfully used in analyzing several projects in the Delta. However, DSM2 has a limited ability to simulate three-dimensional processes such as gravitational circulation which is known to increase with sea level rise in the estuaries. Therefore, it is imperative that DSM2 be recalibrated or corroborated based on a dataset that accurately represents the conditions in the Delta under sea level rise. Since the proposed conditions are hypothetical, the best available approach to estimate the Delta hydrodynamics would be to simulate higher dimensional models which can resolve the three-dimensional processes well. These models would generate the data sets needed to corroborate or recalibrate DSM2 under the proposed conditions so that it can simulate the hydrodynamics and salinity transport with reasonable accuracy.

## 5.B.A.3.3 Modeling Tools

### 5.B.A.3.3.1 DSM2

DSM2 is a one-dimensional hydrodynamics, water quality and particle tracking simulation model used to simulate hydrodynamics, water quality, and particle tracking in the Sacramento-San Joaquin Delta (DWR, 2002). DSM2 represents the best available planning model for Delta tidal hydraulics and salinity modeling. It is appropriate for describing the existing conditions in the Delta, as well as performing simulations for the assessment of incremental environmental impacts caused by facilities and operations. The DSM2 model has three separate components: HYDRO, QUAL, and PTM. HYDRO simulates one-dimensional hydrodynamics including flows, velocities, depth, and water surface elevations. The HYDRO module is a one-dimensional, implicit, unsteady, open channel flow model that DWR developed from FOURPT, a four-point finite difference model originally developed by the USGS in Reston, Virginia. HYDRO provides the flow input for QUAL and PTM. The QUAL module is a one-dimensional water quality transport model that DWR adapted from the Branched Lagrangian Transport Model originally developed by the USGS in Reston, Virginia. QUAL simulates fate and transport of conservative and non-conservative water quality constituents by solving the one-dimensional advection-dispersion equation in which non-conservative constituent relationships are considered to be governed, in general, by first order rates. Tidal boundary (stage in feet) is applied at Martinez. Flow boundaries are specified at Sacramento, Vernalis, Yolo bypass and

East side streams. Other boundaries include gates and other control structures, diversions, exports and Delta Island Consumptive Use (DICU). QUAL uses EC boundary specified at Martinez and other boundary inflow locations mentioned above.

#### 5.B.A.3.3.2 UnTRIM-3D

Sea level rise is known to alter the transport processes in the estuaries. Processes such as the gravitational circulation are affected by the resulting changes in the density gradients under the sea level rise. DSM2 does not explicitly simulate these transport processes unlike the other higher order models, such as UnTRIM-3D. Therefore, results from the UnTRIM-3D were used to corroborate and fine tune the transport processes in DSM2 under the sea level rise conditions.

UnTRIM Bay-Delta Model, a three-dimensional hydrodynamics and water quality model was used to simulate the sea level rise effects on hydrodynamics and salinity transport under the historical operations in the Delta. The results from the UnTRIM model were used to corroborate RMA and DSM2 models so that they simulate the effect of sea level rise accurately.

A complete description of the UnTRIM Bay-Delta model can be found in MacWilliams et al. (2009). The UnTRIM model solves the three-dimensional Navier-Stokes equations on an unstructured grid in the horizontal plane. The boundaries between vertical layers are at fixed elevations, and cell heights can be varied vertically to provide increased resolution near the surface or other vertical locations. Volume conservation is satisfied by a volume integration of the incompressible continuity equation, and the free-surface is calculated by integrating the continuity equation over the depth, and using a kinematic condition at the free-surface as described in Casulli (1990). The numerical method allows full wetting and drying of cells in the vertical and horizontal directions. The governing equations are discretized using a finite difference – finite volume algorithm.

The UnTRIM San Francisco Bay-Delta model (UnTRIM Bay-Delta model) is a three-dimensional hydrodynamic model of San Francisco Bay and the Sacramento-San Joaquin Delta, which has been developed using the UnTRIM hydrodynamic model (MacWilliams et al., 2007; MacWilliams et al., 2008; MacWilliams et al., 2009). The UnTRIM Bay-Delta model extends from the Pacific Ocean through the entire Sacramento-San Joaquin Delta (Figure 2-1). The UnTRIM Bay-Delta model takes advantage of the grid flexibility allowed in an unstructured mesh by gradually varying grid cell sizes, beginning with large grid cells in the Pacific Ocean and gradually transitioning to finer grid resolution in the smaller channels of the Sacramento-San Joaquin Delta. The model calibration and validation results (MacWilliams et al., 2008; MacWilliams et al. 2009) demonstrate that the UnTRIM Bay-Delta model is accurately predicting flow, stage, and salinity in San Francisco Bay and the Sacramento-San Joaquin Delta under a wide range of hydrologic conditions and is suitable for evaluating the potential salinity impacts resulting from sea level rise.

### 5.B.A.3.4 CWF Corroboration Scenario

The evaluation of CWF is performed at year 2030. A sea level rise of 15cm was assumed at year 2030 for the CWF BA. DSM2 was corroborated for a 15cm sea level rise scenario using results from UnTRIM model simulation, which assumed 15 cm increase in the mean sea level without any change in the amplitude at the ocean end.

### 5.B.A.3.5 Corroboration Methodology

Maintaining consistent grid and boundary conditions between the higher dimensional model and DSM2 model for each scenario is critical for successful corroboration. The methodology includes building the physical changes into the DSM2 grid and ensuring the boundary conditions for stage, inflow, diversion and gate operations are consistent between DSM2 and the higher dimensional model. Once ensuring the consistency between the two model setups, the results from the higher dimensional model are used to fine tune the DSM2 results.

#### 5.B.A.3.5.1 Corroboration Baseline

DSM2 model from the 2009 mini-calibration is used as the baseline in the corroboration process. The historical boundary conditions are updated to be same as that UnTRIM baseline model. DSM2 stage and EC boundary at Martinez are set equal to the output at Martinez from the UnTRIM baseline model. Figure 2 shows the north Delta portion of the DSM2 grid used for the corroboration baseline.

#### 5.B.A.3.5.2 Physical Changes in DSM2

The DSM2 bathymetry remains unchanged and sea level rise is the only modification.

#### 5.B.A.3.5.3 Boundary Conditions

In order to achieve DSM2 results consistent with the higher dimensional model, the number of differences between the two models in terms of the grid, bathymetry and boundary conditions have to be minimized. Therefore, the historical flow and EC boundaries at all the rim stations and in-Delta locations were set equal to those used in the higher dimensional model. Further, the stage and EC boundary conditions at Martinez used in the DSM2 model were set equal to the simulated outputs at Martinez from higher dimensional model used in the corroboration process.

#### 5.B.A.3.5.4 Information from Higher Dimensional Models

In the corroboration scenario, correlations capturing the changes in stage and EC at Martinez were provided from the UnTRIM model. In addition, to verify the DSM2 results, timeseries of breach flows at all the proposed breach locations, timeseries of tidal flows at key channel locations and timeseries of EC at key channel locations in the Delta were provided based on the UnTRIM results.

#### 5.B.A.3.5.5 Simulation Period for Corroboration

In general the corroboration was performed over a portion of the water years 2002 and 2003.

#### 5.B.A.3.5.6 Corroboration Metrics

During the process of corroboration, changes to the DSM2 parameters were made based on computed statistics such that the incremental changes predicted by DSM2 between the baseline and corroboration scenario were similar to those predicted by higher dimensional model. The metrics used to assess the quality of flow corroboration included incremental change of instantaneous flows in the corroboration model from baseline model at key locations, incremental change of tidally averaged daily flows in the corroboration model from baseline model at key locations, instantaneous flows and tidally averaged net daily flows at key channel locations in the Delta and at breaches. The metrics used to assess the quality of EC corroboration included incremental change of tidally-averaged daily EC from the current conditions model to the corroboration model at key locations in the Delta and the tidally averaged daily EC at key locations in the Delta.

- Incremental change of instantaneous flows from baseline model at key locations
- Incremental change of tidally averaged daily flows from baseline model at key locations
- Tidally averaged daily EC at key locations
- Incremental change of tidally averaged daily EC at key locations

### 5.B.A.3.6 Corroboration of Scenario with 15 cm Sea Level Rise

This section describes the specifics related to the corroboration of DSM2 for the 15 cm sea level rise scenario. UnTRIM model was used in this corroboration process. In this corroboration process, the DSM2 baseline model stayed the same, except the stage and EC boundary conditions at Martinez were from the UnTRIM baseline outputs.

For the sea level rise corroboration, there were no physical changes to the baseline grid. Once again, for the baseline and the sea level rise corroboration run, the boundary conditions and the model setup were ensured to be consistent between DSM2 and UnTRIM models.

#### 5.B.A.3.6.1 Boundary Conditions

The boundary conditions under DSM2 baseline model were consistent with the UnTRIM baseline model. The stage and EC boundary conditions at Martinez used in the DSM2 model were set equal to the simulated outputs at Martinez from the corresponding UnTRIM model. Table 1 summarizes the list of boundary conditions that are used in the DSM2 model for the sea level rise corroboration runs.

#### 5.B.A.3.6.2 Simulation Period for Sea Level Rise Corroboration Scenarios

The UnTRIM runs were simulated from October 2001 to Dec 2002 period. The period of corroboration was from January 2002 through December 2002, although the simulations were initiated in October 2001. For this period, the UnTRIM model was run with the assumed changes in the mean sea level at the ocean boundary under the 15 cm scenario. The flow and EC results from the UnTRIM model were used to corroborate DSM2 with full boundary condition changes incorporated. During the process of corroboration, changes to the DSM2 parameters were performed based on computed statistics such that the incremental changes predicted by DSM2 between the baseline and sea level rise scenarios were similar to those predicted by UnTRIM.

### 5.B.A.3.6.3 Parameters Adjusted for the Corroboration

The consistency in the boundary conditions between the two models ensured that DSM2 HYDRO runs for the sea level rise scenarios resulted in a good match with UnTRIM in terms of the incremental changes in the flow without any changes to the model parameters. Based on the initial QUAL results, dispersion factors were modified for a few channels between Sherman Lake and Rio Vista on the Sacramento River in DSM2 to match the incremental change in salinity in the UnTRIM results. Since DSM2 does not capture the increased gravitational circulation caused by the sea level rise as in UnTRIM, increasing the dispersion factors in DSM2 compensates for the higher tidal dispersion caused by the sea level rise. Table 2 shows the DSM2 channels with the modified dispersion factors for sea level rise scenarios along with the values under the baseline.

### 5.B.A.3.6.4 Corroboration Results

The DSM2 results from the final sea level rise corroboration runs were compared with the UnTRIM results. Figure 1 compares the average incremental change in tidally-averaged EC at several key locations in the Delta for 15 cm sea level rise scenario simulated in DSM2 and UnTRIM models. The results show that DSM2 matches UnTRIM reasonably well in terms of the direction and magnitude of the average change at most locations.

Figures 2, 3, 4 and 5 show the timeseries of incremental change in EC between DSM2 and UnTRIM at Collinsville, Emmaton, Jersey Point and Old River at Rock Slough locations for the 15 cm sea level rise scenario, respectively. In general, the incremental change in DSM2 matches well with UnTRIM. Even though the incremental change in EC from DSM2 is slightly lower at Collinsville, it matches well at Emmaton. At Jersey Point and Old River at Rock Slough DSM2 shows higher incremental change than UnTRIM. Comparing the DSM2 and UnTRIM baseline models with the observed data it was found that UnTRIM was under-predicting the salinity in the central and south Delta. It was found that UnTRIM salinity result at Jersey Point was about 20% below the observed values and DSM2 was about 20% higher than the observed values. South Delta salinities simulated in DSM2 matched well with the observed data. For this reason, the UnTRIM results in this region of the Delta were mainly used to capture the trends and not necessarily to match the magnitude of the change while corroborating DSM2 sea level rise scenarios. Figures 6 through 15 compare incremental changes in EC from DSM2 to the incremental changes in UnTRIM at other key locations in the Delta.

**Table 1. Summary of DSM2 Boundary Conditions for the Corroboration Baseline**

| Boundary Location | DSM2 Node/ Reservoir | Boundary Type |
|---|---|---|
| Calaveras | 21 | flow/EC |
| Cosumnes | 446 | flow/EC |
| Mokelumne | 447 | flow/EC |
| North Bay | 273 | Diversion |
| Yolo | 316 | flow/EC |
| Sacramento | 330 | flow/EC |
| Vernalis | 17 | flow/EC |
| Martinez | 361 | Stage/EC |
| CVP | 181 | Diversion |
| Green Valley Creek | 369 | flow/EC |
| Suisun Creek | 396 | flow/EC |
| Ledgewood Creek | 392 | flow/EC |
| Laurel Creek | 368 | flow/EC |
| Fairfield WWTP | 400 | flow/EC |
| Roaring River Duck Club | 418 | flow/EC |
| Morrow Island Duck Club | 384 | Diversion |
| Montezuma Sl West Duck Club | 428 | flow/EC |
| Montezuma Sl East Duck Club | 420 | flow/EC |
| Montezuma Sl Middle Duck Club | 422 | flow/EC |
| Nurse Sl Duck Club | 406 | flow/EC |
| Suisun Sl Duck Club | 375 | flow/EC |
| Boynton Sl Tidal Marsh | 400 | Precipitation/EC |
| Peytonia Sl Tidal Marsh | 371 | Precipitation/EC |
| Hill Sl Tidal Marsh | 395 | Precipitation/EC |
| First Mallard Sl Tidal Marsh | 373 | Precipitation/EC |
| Cutoff Sl Tidal Marsh | 399 | Precipitation/EC |
| Beldons Landing Tidal Marsh | 425 | Precipitation/EC |

**Table 2. Modified DSM2 Channel Dispersion Factors to Compensate for the Increased Tidal Dispersion under 15 cm Sea Level Rise Scenario**

| | Channel Dispersion Factors | |
|---|---|---|
| **DSM2 Channel** | **Baseline** | **15cm Sea Level Rise** |
| 431 | 0.05 | 0.08 |
| 432 | 0.20 | 0.20 |
| 433 | 0.20 | 0.25 |
| 434 | 0.50 | 0.55 |

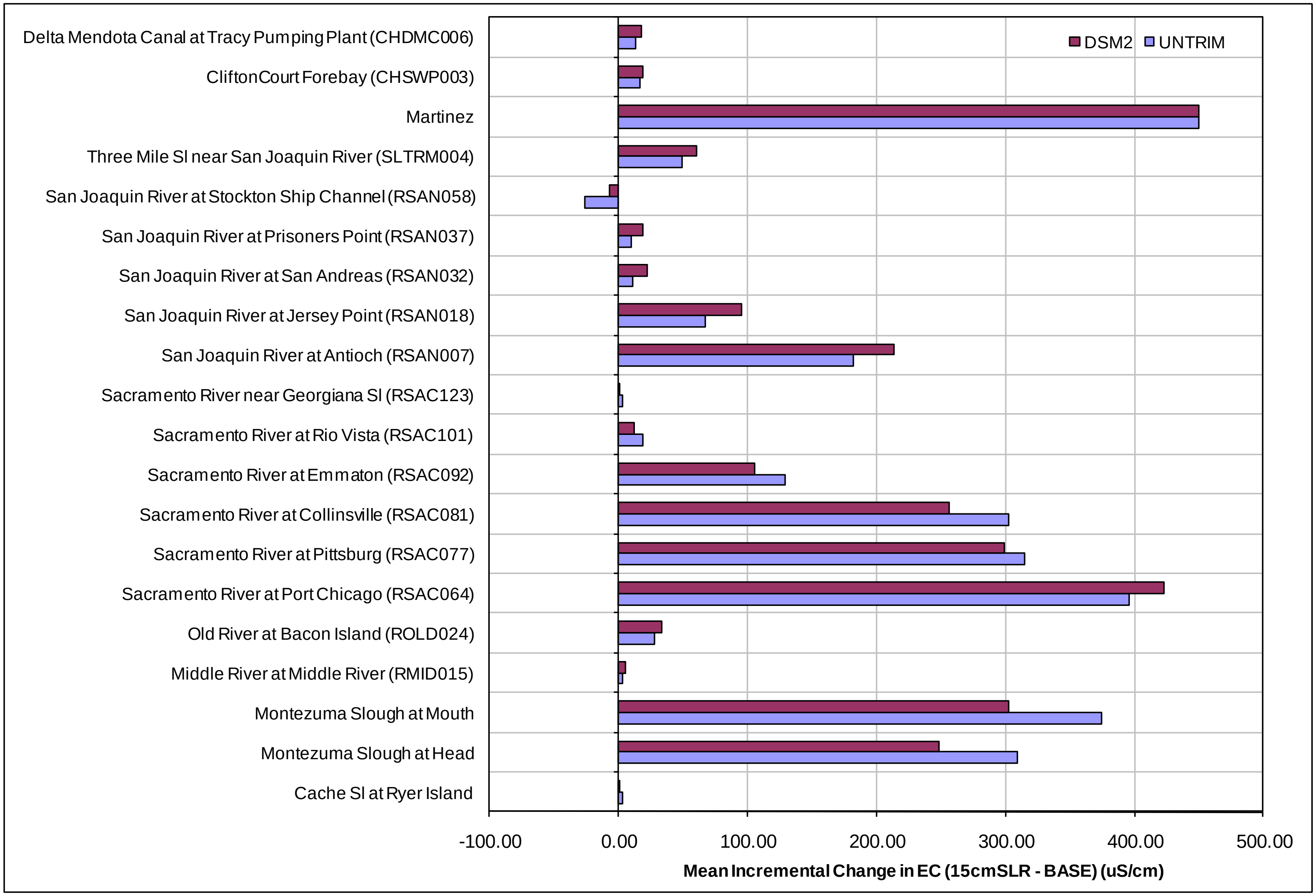


**Figure 1: Comparison of average incremental change in tidally averaged EC in 15cm SLR scenario from the baseline between DSM2 and UNTRIM**

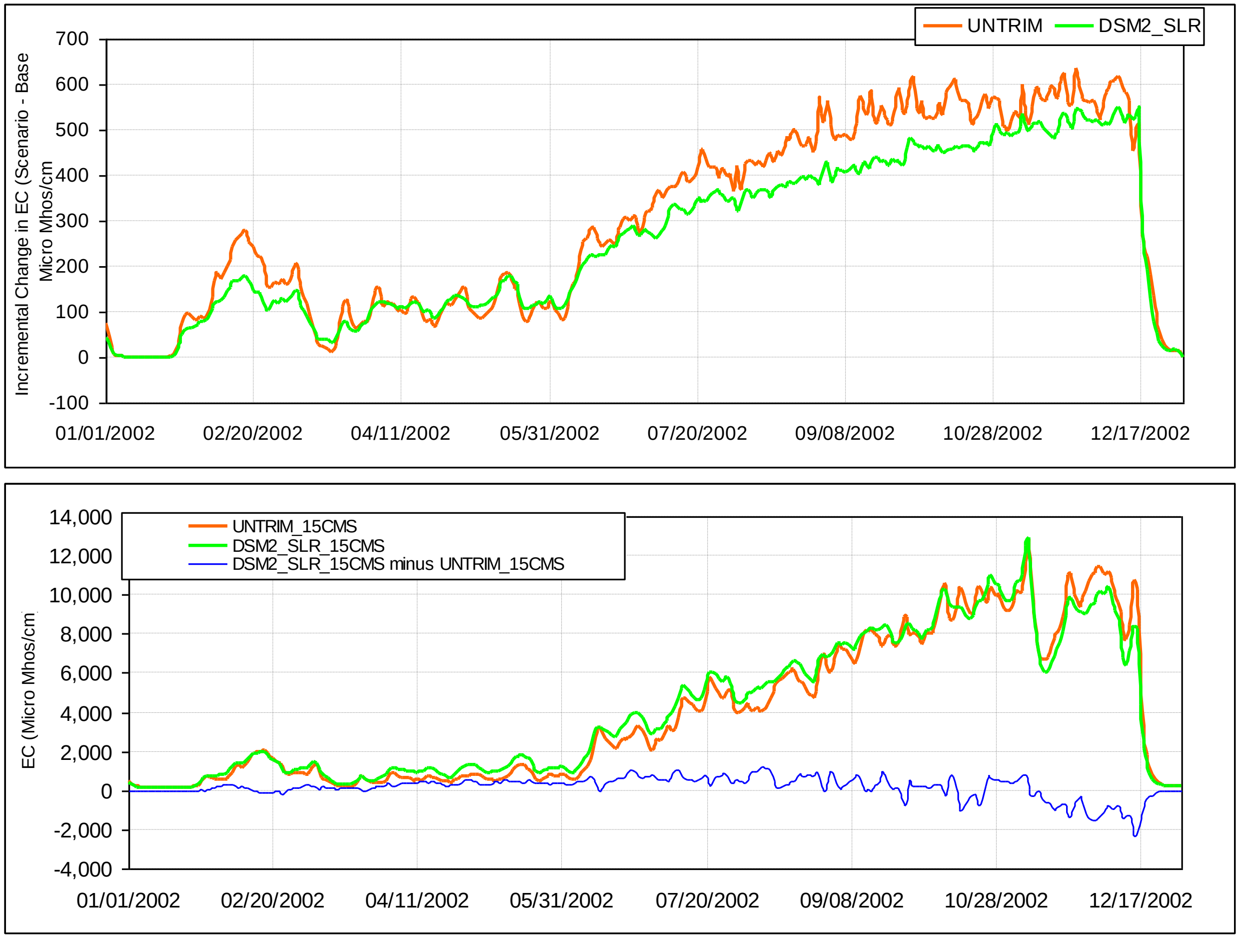


**Figure 2: Comparison of Tidally-Averaged Daily EC and the Incremental Change in the Daily EC between the 15 cm Sea Level Rise and the Current Conditions Scenario from UnTRIM Model and DSM2 Model for Sacramento River at Collinsville Location**

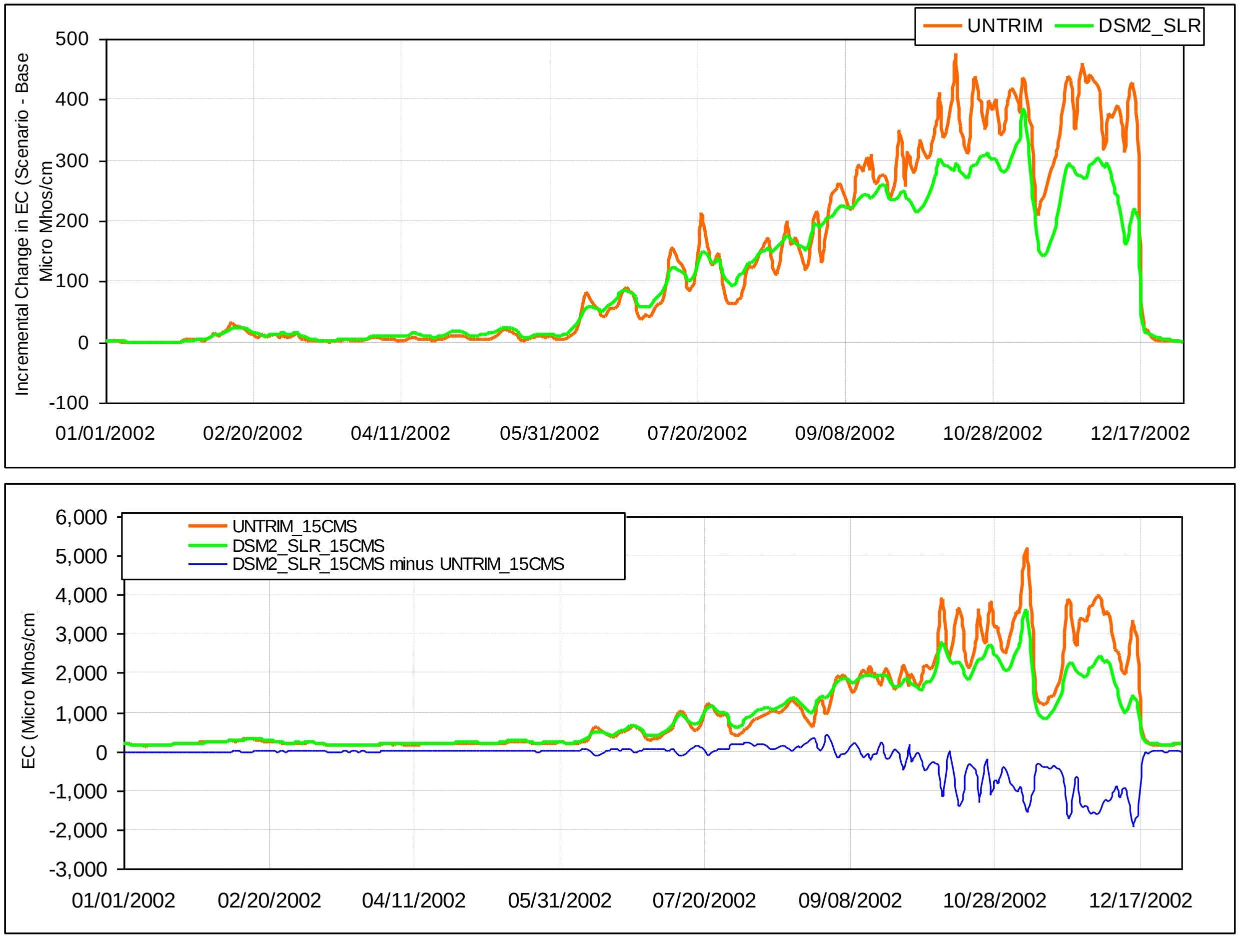


**Figure 3: Comparison of Tidally-Averaged Daily EC and the Incremental Change in the Daily EC between the 15 cm Sea Level Rise and the Current Conditions Scenario from UnTRIM Model and DSM2 Model for Sacramento River at Emmaton Location**

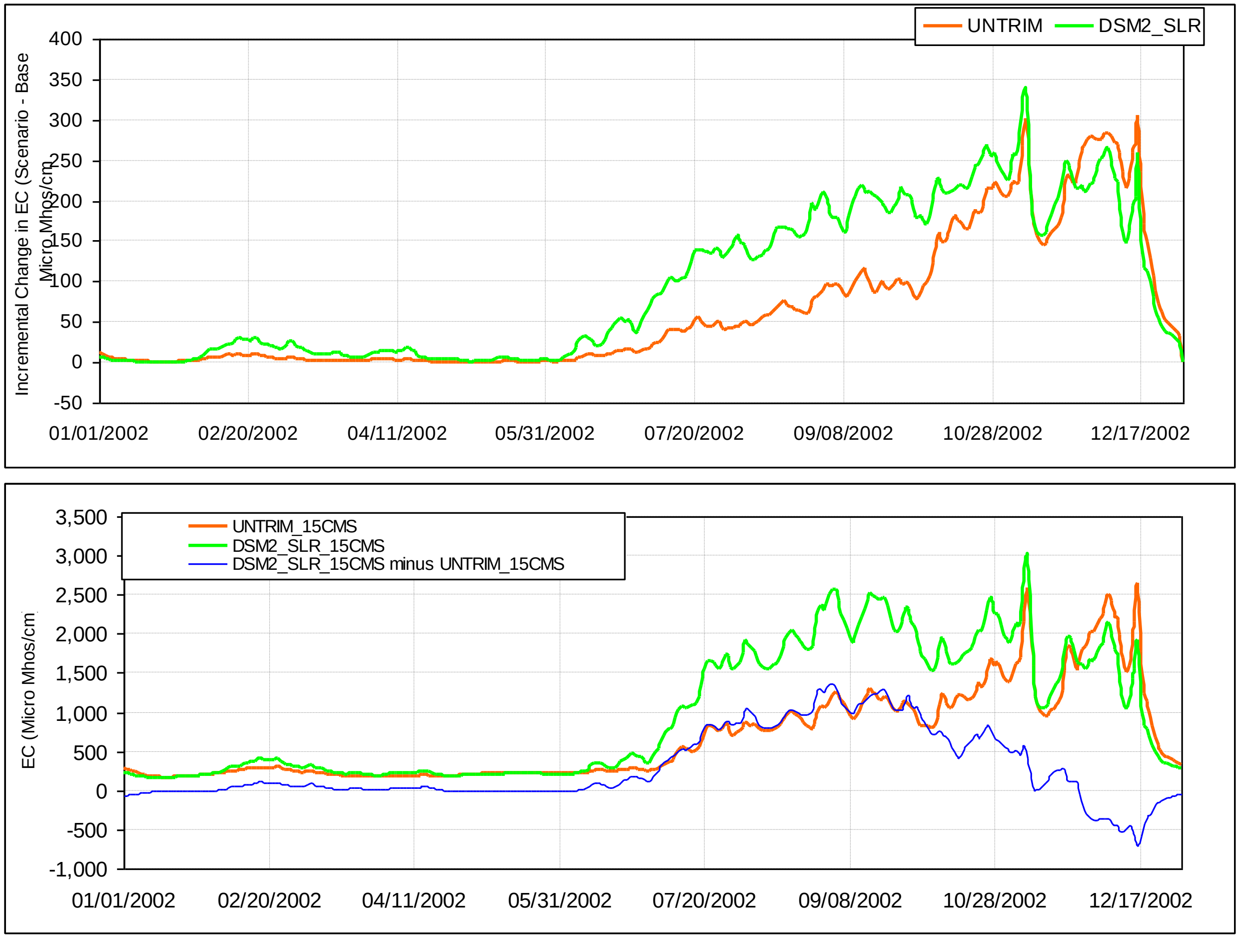


**Figure 4: Comparison of Tidally-Averaged Daily EC and the Incremental Change in the Daily EC between the 15 cm Sea Level Rise and the Current Conditions Scenario from UnTRIM Model and DSM2 Model for San Joaquin River at Jersey Point Location**

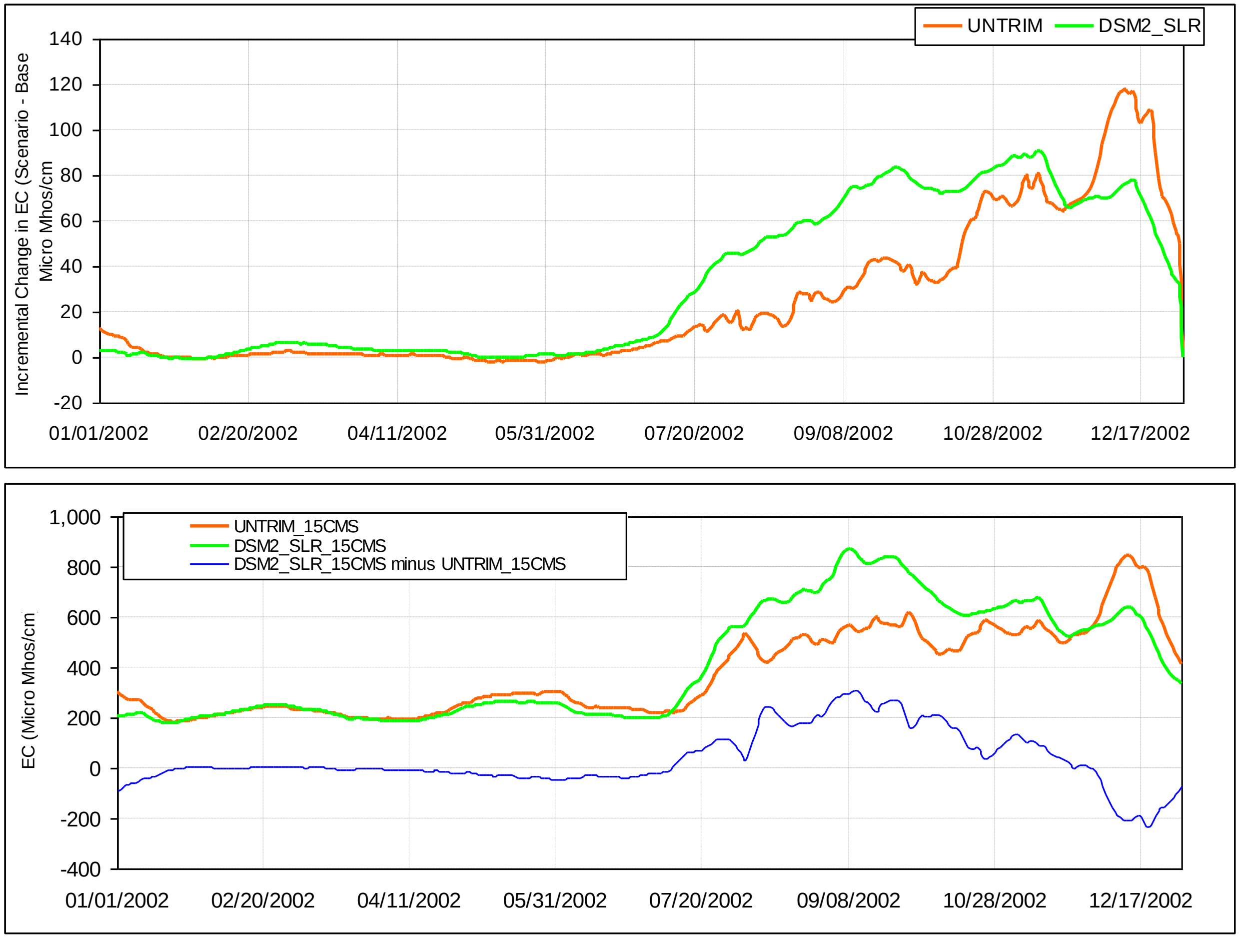


**Figure 5: Comparison of Tidally-Averaged Daily EC and the Incremental Change in the Daily EC between the 15 cm Sea Level Rise and the Current Conditions Scenario from UnTRIM Model and DSM2 Model for Old River at Rock Slough Location**

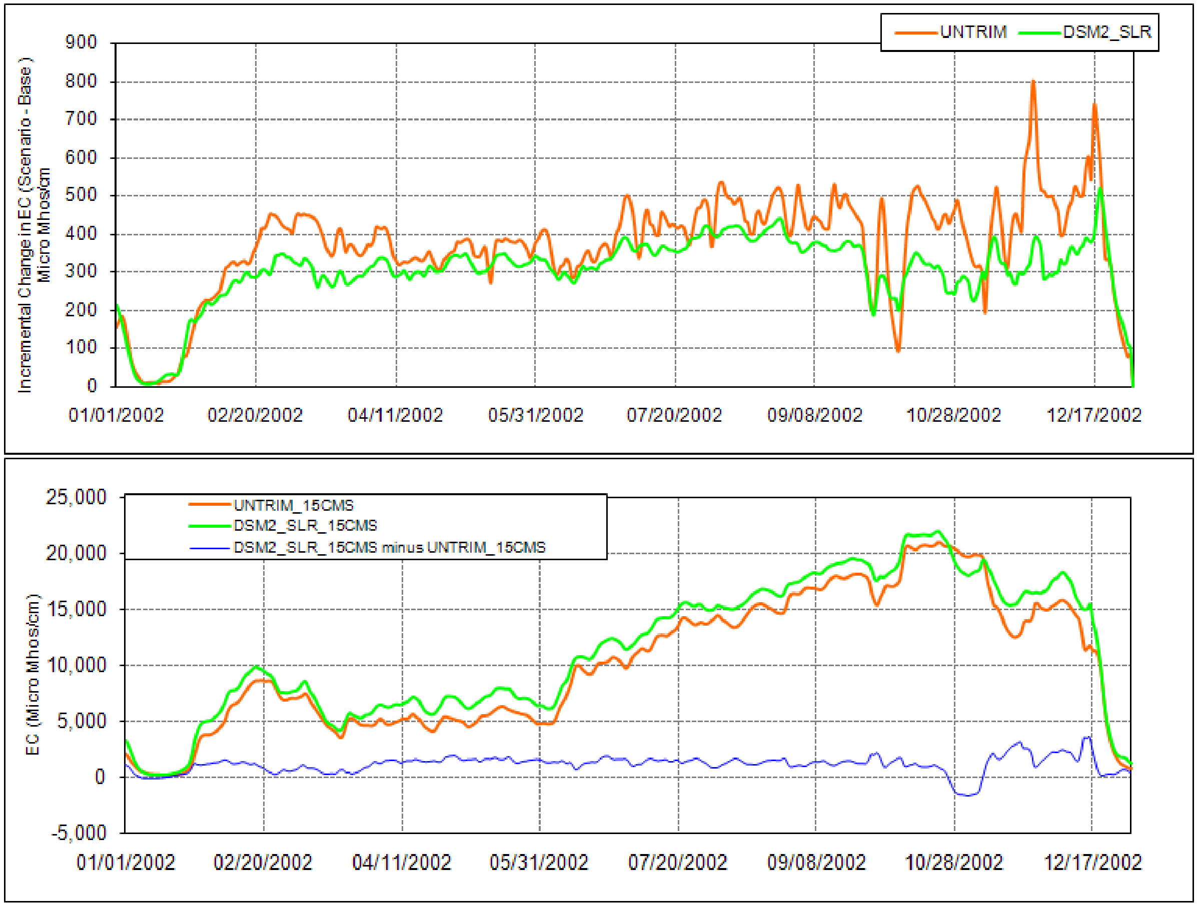


**Figure 6: Comparison of Tidally-Averaged Daily EC and the Incremental Change in the Daily EC between the 15cm SLR Scenario and the Current Conditions Scenario from UNTRIM Model and DSM2 Model for Montezuma Slough at Mouth Location.**

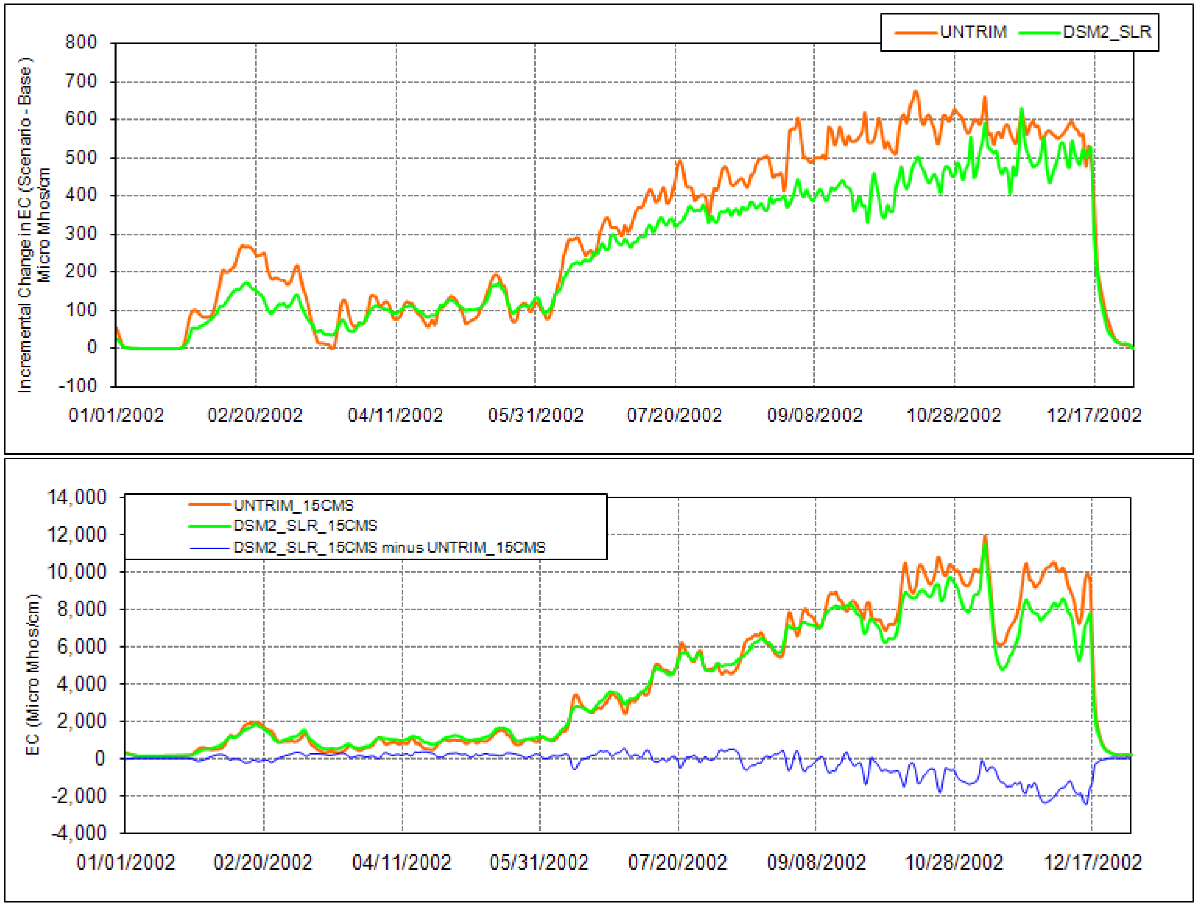


**Figure 7: Comparison of Tidally-Averaged Daily EC and the Incremental Change in the Daily EC between the 15cm SLR Scenario and the Current Conditions Scenario from UNTRIM Model and DSM2 Model for Montezuma Slough at Head Location.**

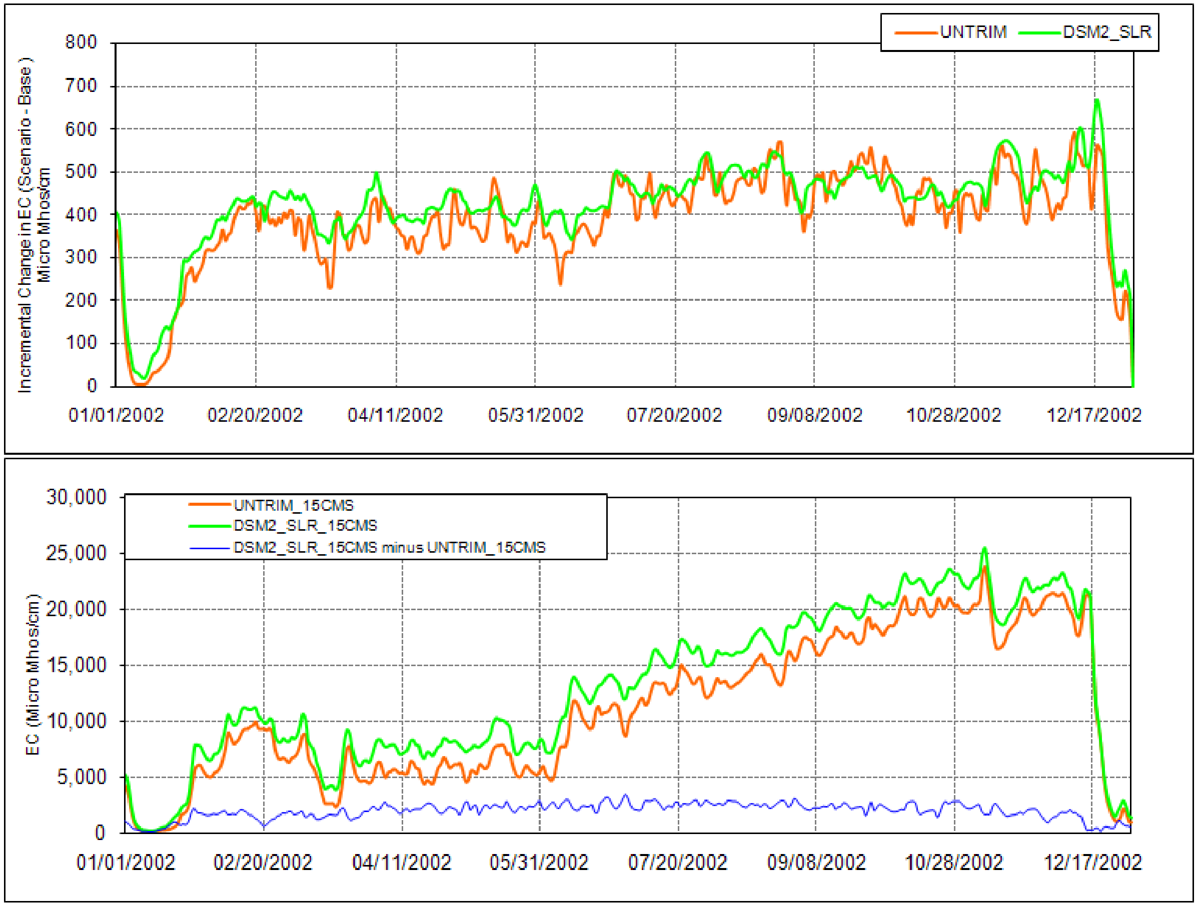


**Figure 8: Comparison of Tidally-Averaged Daily EC and the Incremental Change in the Daily EC between the 15cm SLR Scenario and the Current Conditions Scenario from UNTRIM Model and DSM2 Model for Sacramento River at Port Chicago Location.**

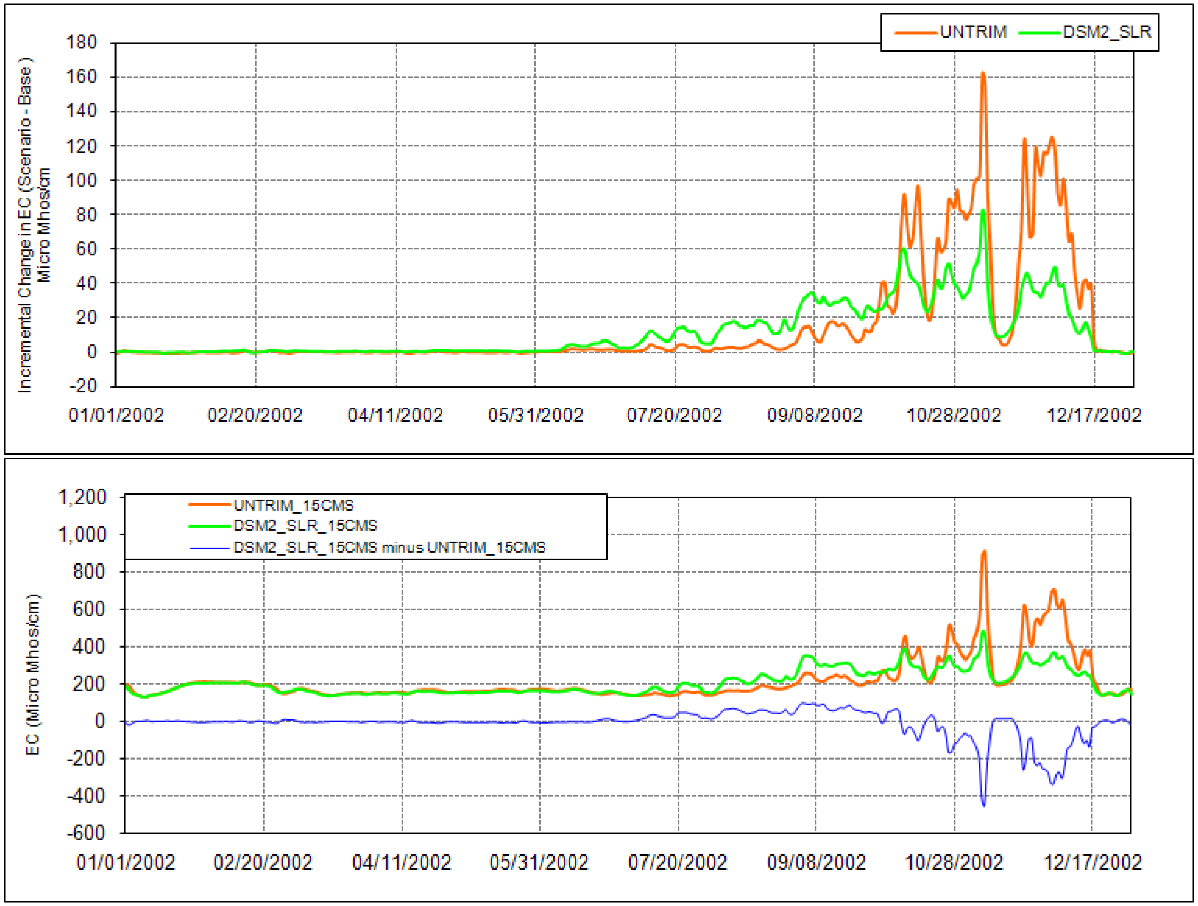


**Figure 9: Comparison of Tidally-Averaged Daily EC and the Incremental Change in the Daily EC between the 15cm SLR Scenario and the Current Conditions Scenario from UNTRIM Model and DSM2 Model for Sacramento River at Rio Vista Location.**

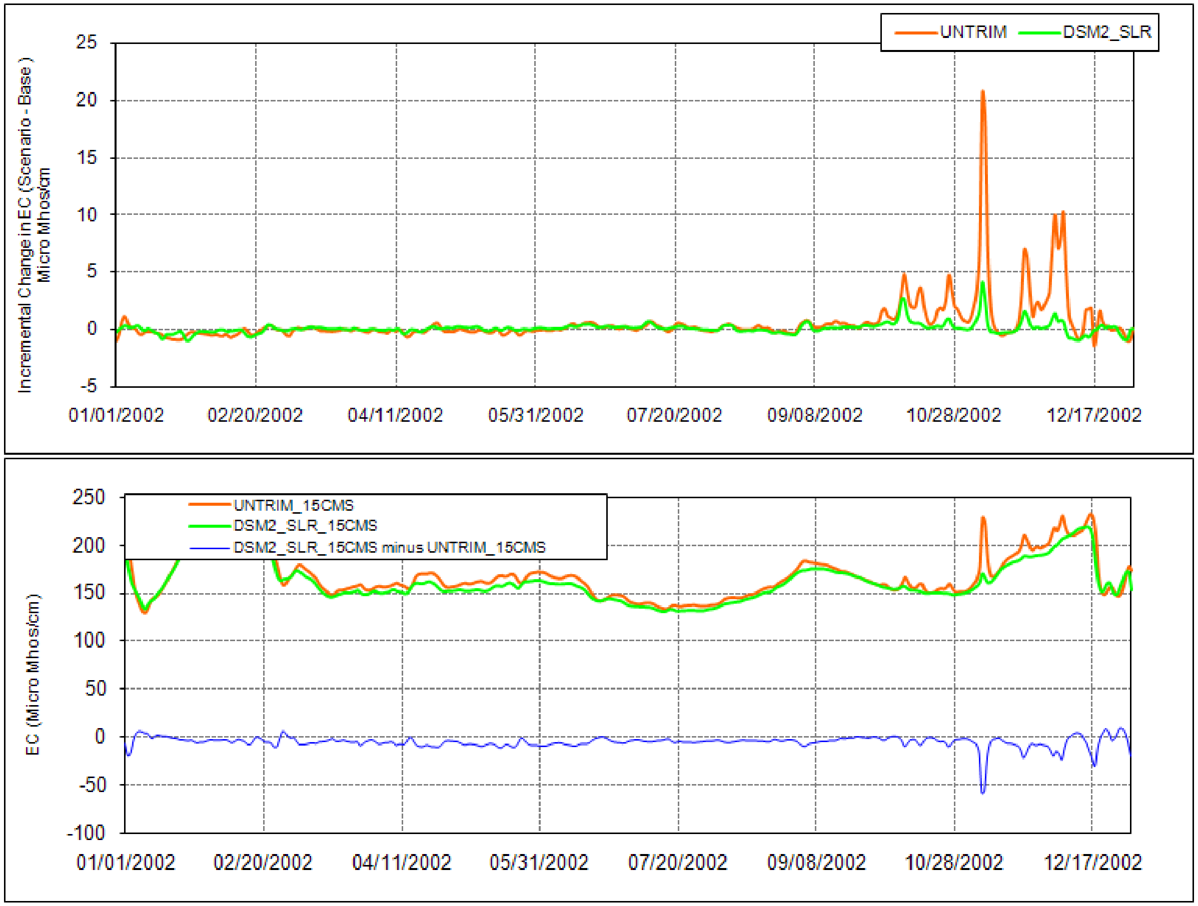


**Figure 10: Comparison of Tidally-Averaged Daily EC and the Incremental Change in the Daily EC between the 15cm SLR Scenario and the Current Conditions Scenario from UNTRIM Model and DSM2 Model for Cache Slough at Ryer Island Location.**

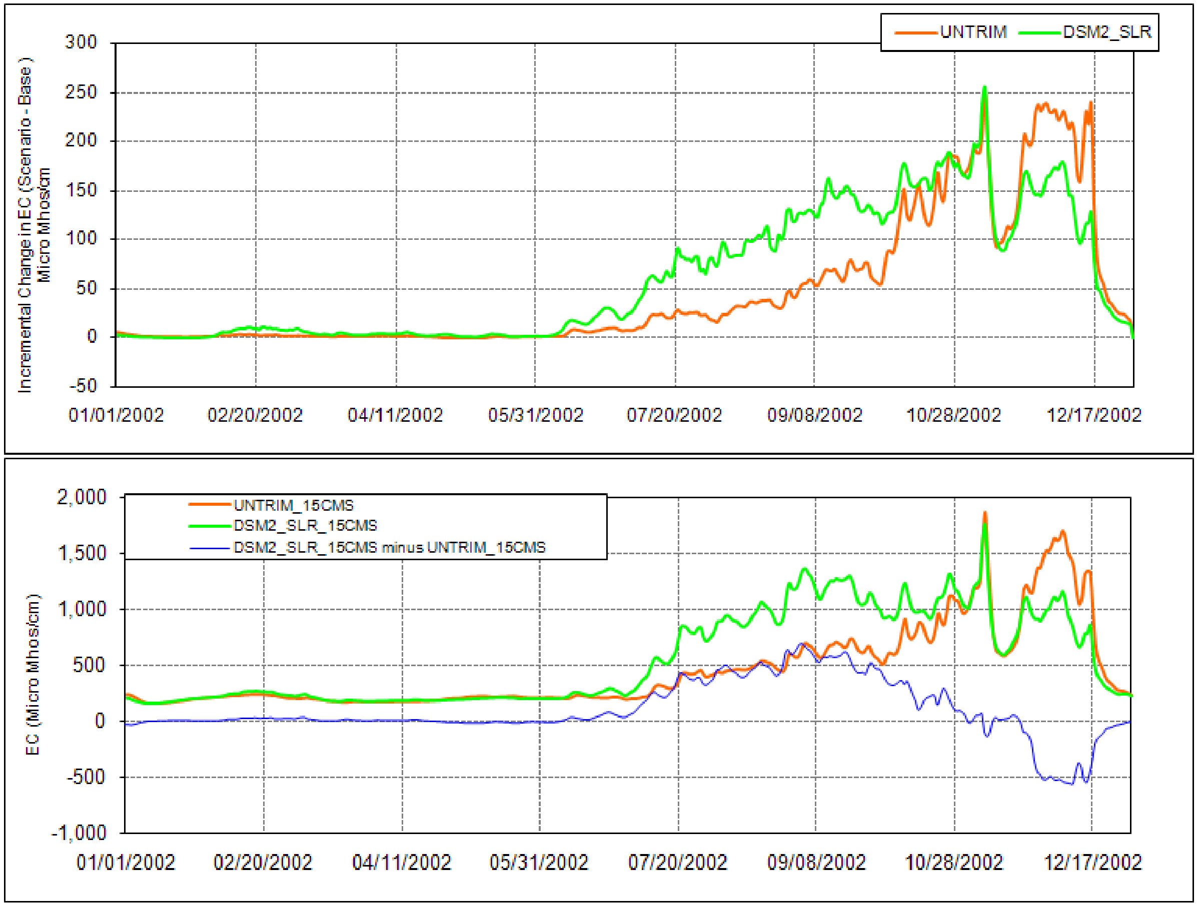


**Figure 11: Comparison of Tidally-Averaged Daily EC and the Incremental Change in the Daily EC between the 15cm SLR Scenario and the Current Conditions Scenario from UNTRIM Model and DSM2 Model for Three Mile Slough at San Joaquin River Location.**

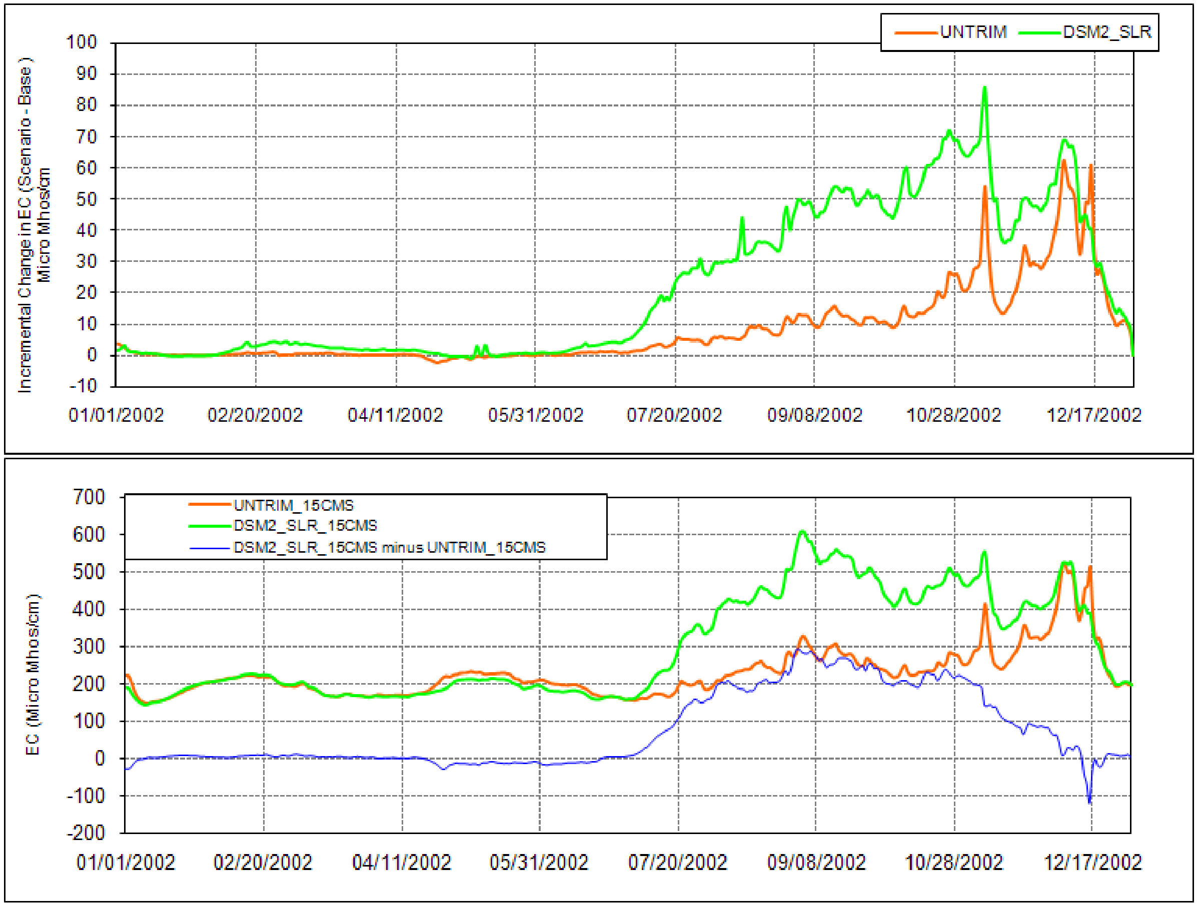


**Figure 12: Comparison of Tidally-Averaged Daily EC and the Incremental Change in the Daily EC between the 15cm SLR Scenario and the Current Conditions Scenario from UNTRIM Model and DSM2 Model for San Joaquin River at San Andreas Location.**

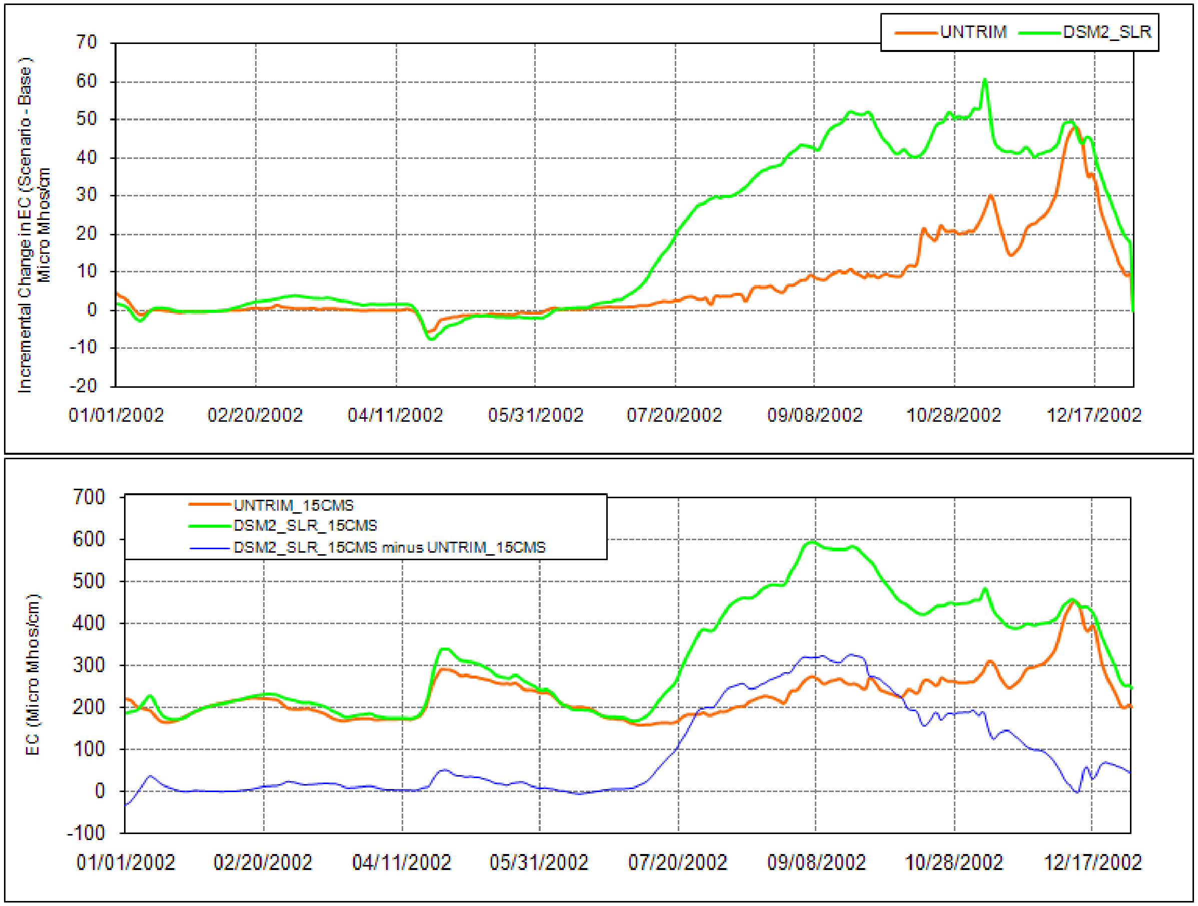


**Figure 13: Comparison of Tidally-Averaged Daily EC and the Incremental Change in the Daily EC between the 15cm SLR Scenario and the Current Conditions Scenario from UNTRIM Model and DSM2 Model for San Joaquin River at Prisoners Point Location.**

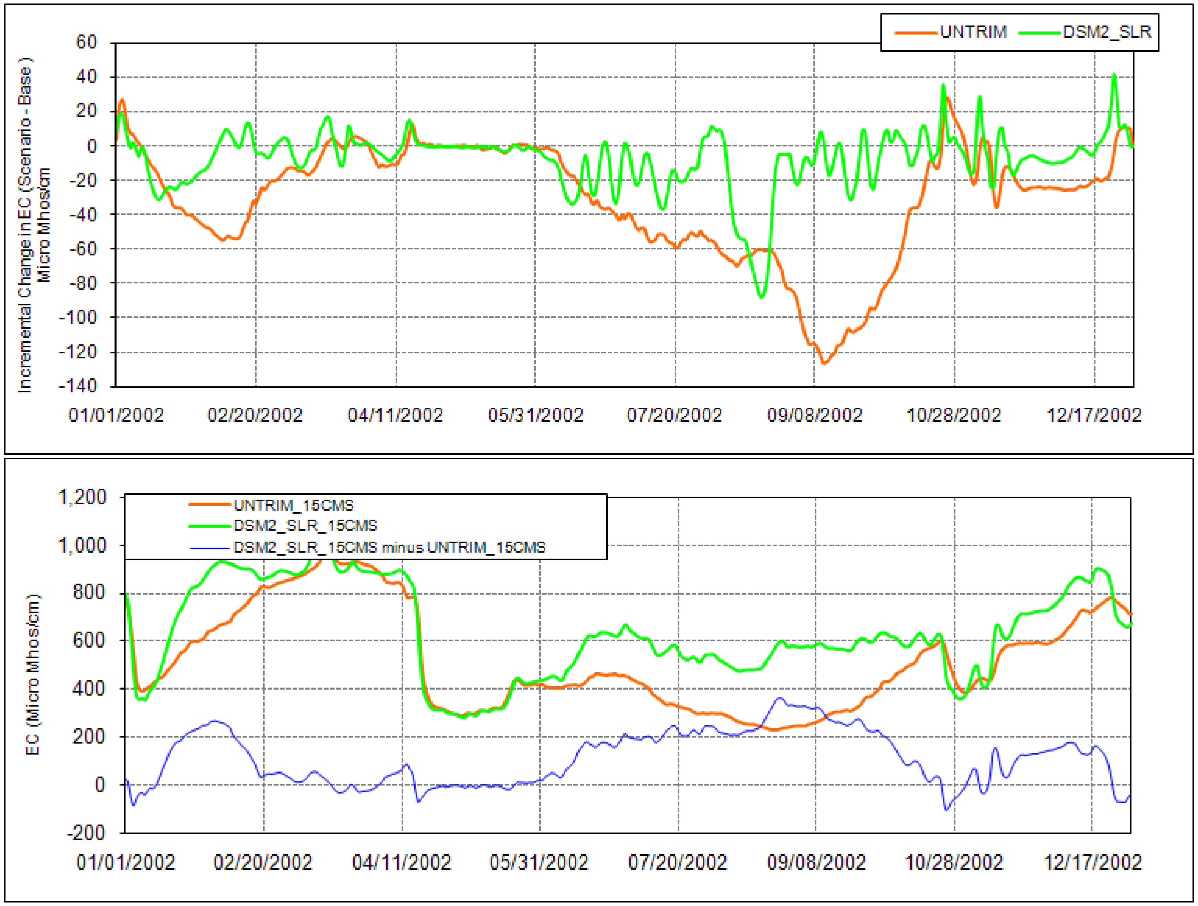


**Figure 14: Comparison of Tidally-Averaged Daily EC and the Incremental Change in the Daily EC between the 15cm SLR Scenario and the Current Conditions Scenario from UNTRIM Model and DSM2 Model for San Joaquin River at Stockton Location.**

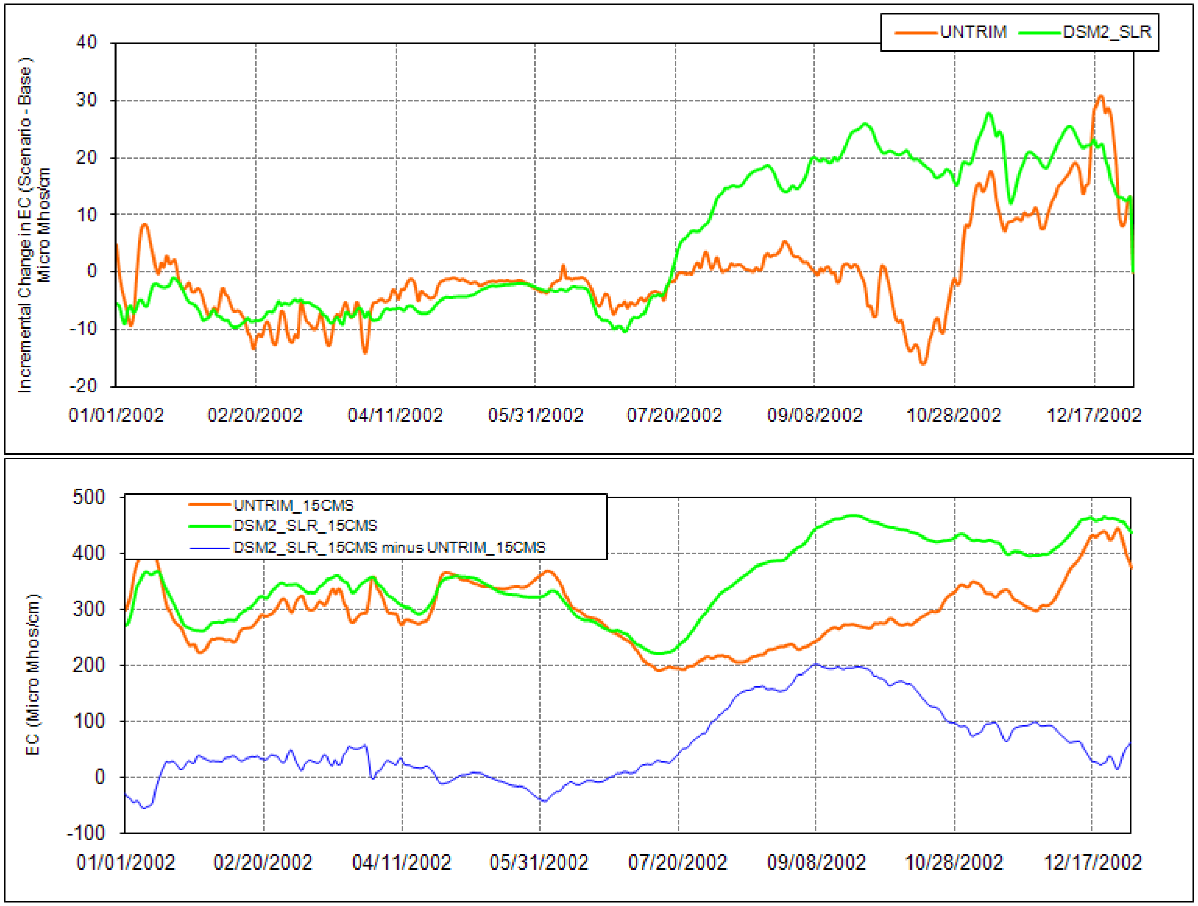


**Figure 15: Comparison of Tidally-Averaged Daily EC and the Incremental Change in the Daily EC between the 15cm SLR Scenario and the Current Conditions Scenario from UNTRIM Model and DSM2 Model for Middle River at Middle River Location.**