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

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Chapter 3

DSM2 Extension: A GIS-Based Approach

Authors: **Ines Ferreira, P.E.**
Nicky Sandhu, P.E.
Delta Modeling Section
Bay-Delta Office
California Department of Water Resources

DEPARTMENT OF WATER RESOURCES

STATE OF CALIFORNIA

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3 DSM2 Extension: A GIS-Based Approach

3.1 Introduction

As with other hydrodynamic and hydraulic models, DSM2 (Delta Simulation Model 2) requires boundary conditions to fully define and drive the system; upstream boundary conditions are usually provided as flow hydrographs while downstream boundary conditions are given as water-surface elevation. Additionally, boundaries are located where observed data is available and are located away from areas of interest that might influence the boundary conditions. For water quality simulations, constituent concentrations must also be provided at all boundaries. In a tidal system, such as the Delta, where most of the salinity originates in the ocean, the salt concentration at the downstream boundary is crucial because it drives the water quality conditions in the Delta.

Situated at the eastern end of the Carquinez Strait, Martinez is the location of the downstream (western) boundary condition for DSM2. While the waterways of the legal Sacramento-San Joaquin Delta are fully contained within the DSM2 boundaries (Figure 3-1), depending on the details of a particular study, the boundary condition location at Martinez can be less than ideal, as we discuss below.

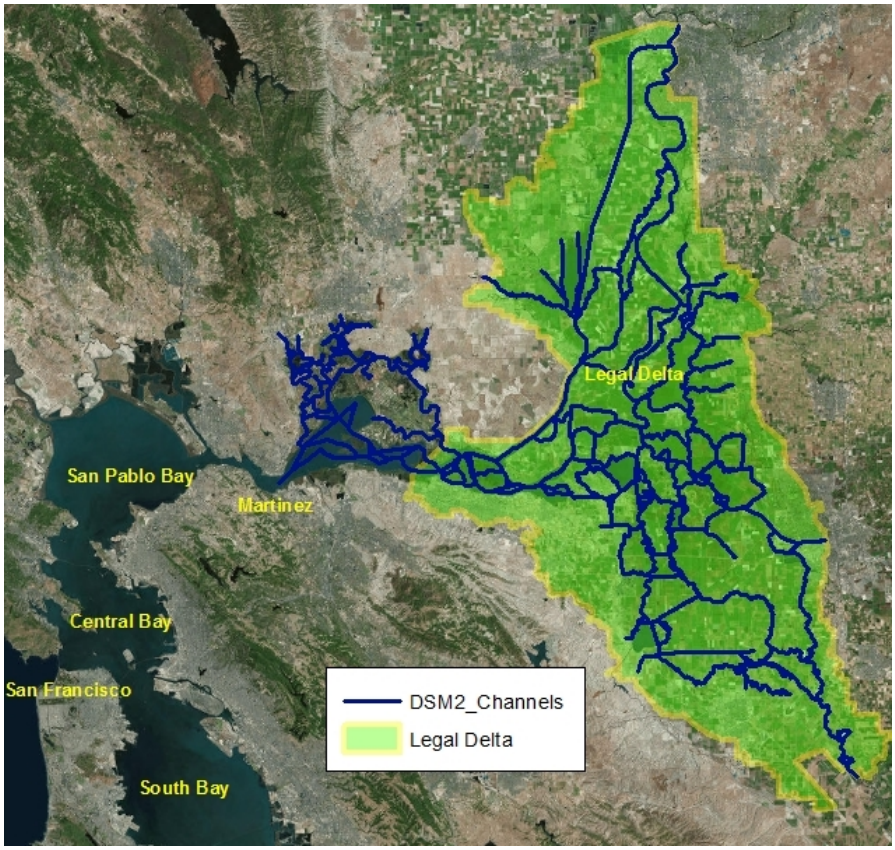


Figure 3-1 Map of Area Modeled Including Legal Boundaries of the Sacramento-San Joaquin Bay-Delta

This project investigates a method for extending the DSM2 grid to the Golden Gate. The method uses a one-dimensional grid, extensive and detailed geoprocessing of geometry data, and sophisticated calibration software. The goal of this grid extension is to reflect the volume of water and salinity transported from the Golden Gate to Martinez for Delta simulations, and it is not intended to provide a detailed model of hydrodynamics and salinity in San Francisco Bay. Preliminary results show promise that the method presented in this chapter can be applied successfully.

3.2 Motivation

DSM2 is generally run in one of three modes: historical, planning, or real-time forecasting. For historical models, the location of the DSM2 downstream boundary conditions at Martinez is adequate for the periods in which observed data at Martinez is available.

Planning studies, however, are the most frequent studies for which DSM2 is used. Planning studies are simulations based on the historical hydrology and infrastructure that are modified to reflect a specific level of development. Planning studies are used to evaluate the effects of proposed changes to regulatory constraints or the physical system (e.g., new facilities). As such, historical data cannot be used directly, and tidal and salinity boundary conditions at Martinez must be determined prior to running DSM2.

Methods for estimating Martinez boundary conditions have been developed and are used for planning studies. Martinez boundary-condition values are calculated using Delta inflows from planning models, such as CalSim II, which is an operations planning model of the State Water Project (SWP) and the Central Valley Project (CVP), combined with empirical or semi-empirical methods (Anderson and Miller 2005; Ateljevich 2001a, 2001b).

In the case of real-time forecasting, a mixture of recently observed data, forecasted tides based on astronomical tides, and a model of the residual tides are used to predict short-term tides at Martinez (Ateljevich 2000).

Consequently, when a large influx of ocean water is expected and/or the area of interest is close enough to Martinez to influence the boundary values, the boundary condition location at Martinez becomes less than ideal for planning studies. An example of such a study, *Long-Term Salinity Impacts from Permanently Flooding Delta Islands* (Ferreira and Anderson 2013), which has received much attention recently, is the evaluation of the salinity impacts of long-term flooding of Delta islands. Under such circumstances, a large volume of ocean water is expected to be quickly drawn into the Delta and flood the islands, most of which are several feet below mean sea level. Another example of a study that needs an extended boundary is a sea level rise study, which takes into consideration the changes in sea level rise from the ocean as water moves through San Francisco Bay and into the Delta. When the boundary location at Martinez is unsuitable, an extended grid version of DSM2 could provide another tool for these types of studies. Note that the extended grid is intended to represent the volume of water and salt transported from the Golden Gate to Martinez and is not intended to be a detailed model of San Francisco Bay. Because tides at Golden Gate are predominantly astronomical (Ateljevich 2001a), and salinity is relatively constant with small seasonal variation (Walters et al. 1985), Golden Gate is a better location for a downstream boundary. The placing of a DSM2 downstream boundary condition at Golden Gate would allow for a greater variety of studies to be performed. While it is true that the water-surface elevation at San Francisco Bay is affected by the outflow from the Bay-Delta Estuary, this is generally the case when outflows from the Bay-Delta are extremely high. In such occasions, salinity intrusion in the Delta is not a concern.

Given that the extra computational cost is not an issue for using DSM2, one of the main reasons for keeping the boundary at Martinez is that a one-dimensional grid is not considered to be well-suited to

simulate the hydrodynamics and transport within the bays between the Carquinez Strait and the Pacific Ocean.

Accordingly, one of the challenges of moving the DSM2 downstream boundary from Martinez to the ocean is that DSM2 is a one-dimensional model. While the Delta with its intricate network of braided channels, can be successfully modeled for most studies with a one-dimensional model, the regions downstream of Martinez consist of large bays (San Pablo and Central San Francisco bays), which are typically modelled with two- or three-dimensional models.

Nonetheless, the advent and power of a geographic information system (GIS) and the associated geographical data and geoprocessing tools allow us to represent the physical system with an exceptional level of detail and accuracy. Additionally, the calibration of SCHISM (Semi-implicit Cross-scale Hydroscience Integrated System Model), a 3-dimensional hydrodynamic model of the Bay-Delta (previously called Bay-Delta SELFE) developed by the Bay-Delta Office (Ateljevich 2014), has provided a wealth of data that we can use to understand circulation and salt transport and, more importantly, calibrate the extended grid DSM2 model (Ateljevich et al. 2014). Furthermore, the well-established parameter estimation software PEST can also be used to calibrate the extended grid of DSM2.

It is this wealth of data and tools that we exploit to investigate the possibility of extending the DSM2 grid from Martinez to the Golden Gate by representing the embayments west of Martinez as a network of channels and, in doing so, translate, in run-time, the tides and salinity from Golden Gate to the traditional DSM2 boundary at Martinez. Preliminary results are encouraging.

It is important to note that the main goal of this project is to find an efficient way of translating the ocean tides and salinity to Martinez using DSM 2. For this reason, the calibration will focus on water levels and salinity at Martinez and not at the San Francisco Bay region west of Martinez.

This chapter describes current efforts in extending the DSM2 western boundary to the Golden Gate by using GIS and ArcMap. The methodology and some preliminary results of the investigation into the suitability of extending the DSM2 grid from Martinez to the Golden Gate with a one-dimensional grid by using detailed GIS data are presented below.

3.3 Methodology

In the first phase of this project, a lattice grid was created for the San Pablo and Central San Francisco bays. Some of the larger coves and bays along the connection between the San Pablo and Central San Francisco bays and on the eastern edges of the Central San Francisco Bay are modeled as reservoirs, while the South Bay is currently represented as a single reservoir. Figure 3-2 shows the extended grid as configured at the time of this writing.

Light Detection And Ranging (LiDAR) data was utilized to prepare a Digital Elevation Model (DEM) of the Delta and the San Francisco region (Wang and Ateljevich 2012) resulting in a very detailed characterization of the geometry of the region (Figure 3-3). This data, in conjunction with the geoprocessing software and ArcGIS tools, has enabled a very accurate calculation of volume between Martinez and the Golden Gate and is described below.

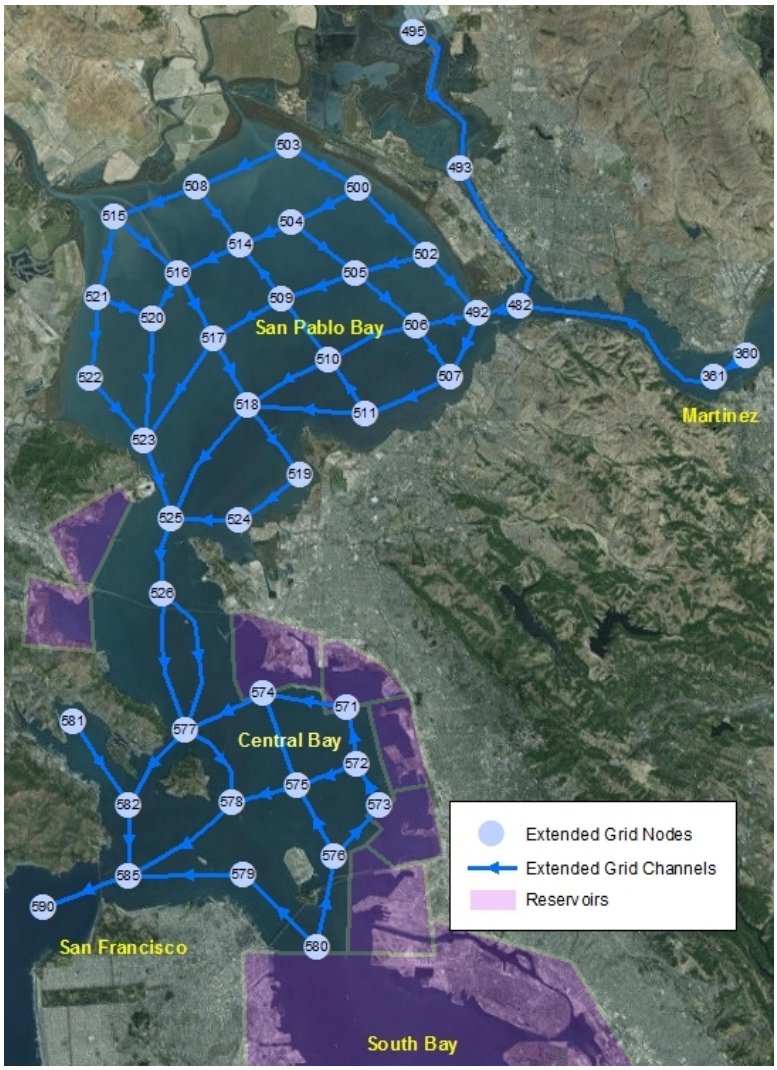


Figure 3-2 DSM2 Grid Extension from Martinez to San Francisco

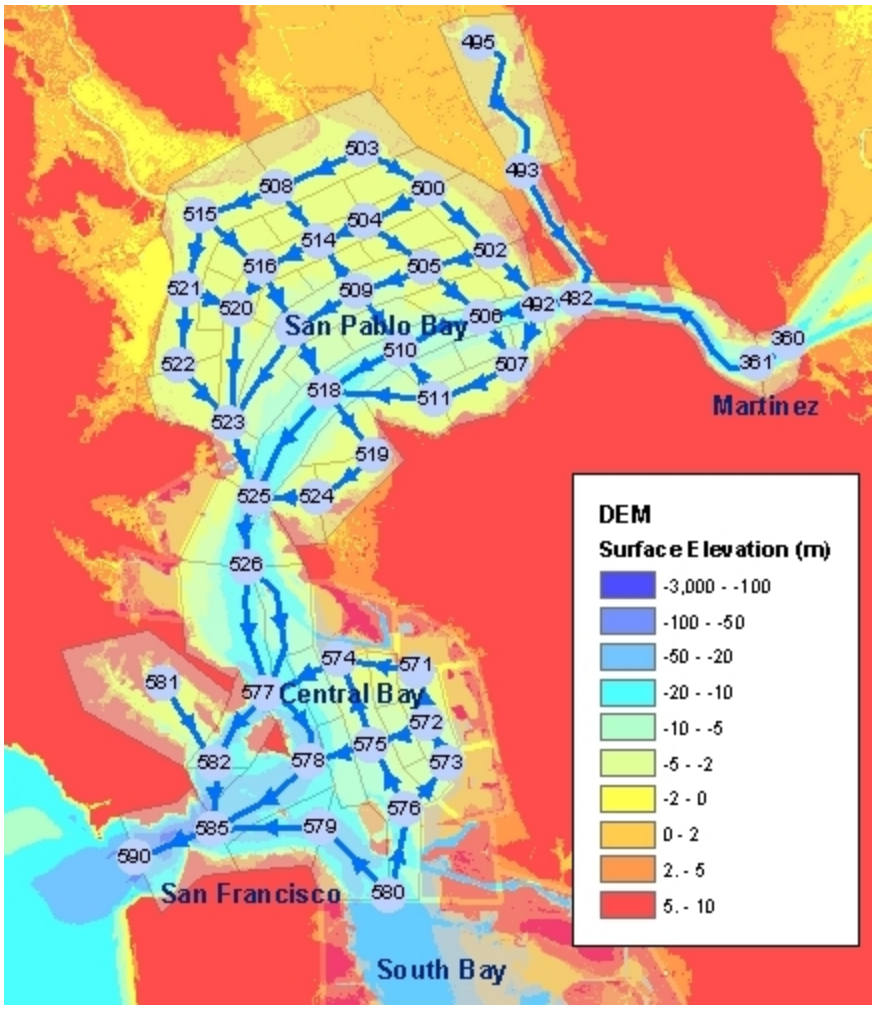


Figure 3-3 Extension Grid showing DEM and "Channel Top Areas"

3.4 Geoprocessing Computations

Extended grid channel reaches and nodes were digitized in ArcMap. Also digitized in ArcMap were the horizontal plane areas, "channel top areas," which are associated with each channel and the cross-section lines. This digitized data was applied to a Python script, which was developed to perform all the necessary geoprocessing computations, which rely heavily on ArcMap geoprocessing tools. Additional computations and code were used to prepare the resulting DSM2 input files.

3.4.1 Cross-Section Profiles

Also computed from the DEM are cross-section profiles for each channel. Each channel has a minimum of two cross sections with additional cross sections added as needed to capture variations in channel width and bathymetry. Cross-sections coordinates are established by intersecting the vertical plane containing the cross-section line with the DEM. Cross-section coordinates from ArcMap are subsequently converted to the required DSM2 format of the channel input file, that is, for each cross section, at various elevations, the associated channel width, flow area, and wetted perimeter are computed and printed to a text file as required by DSM2. Figure 3-4 shows the cross-section coordinate plots for two example cross sections, one at the western end of the Carquinez Strait and the other in San Pablo Bay.

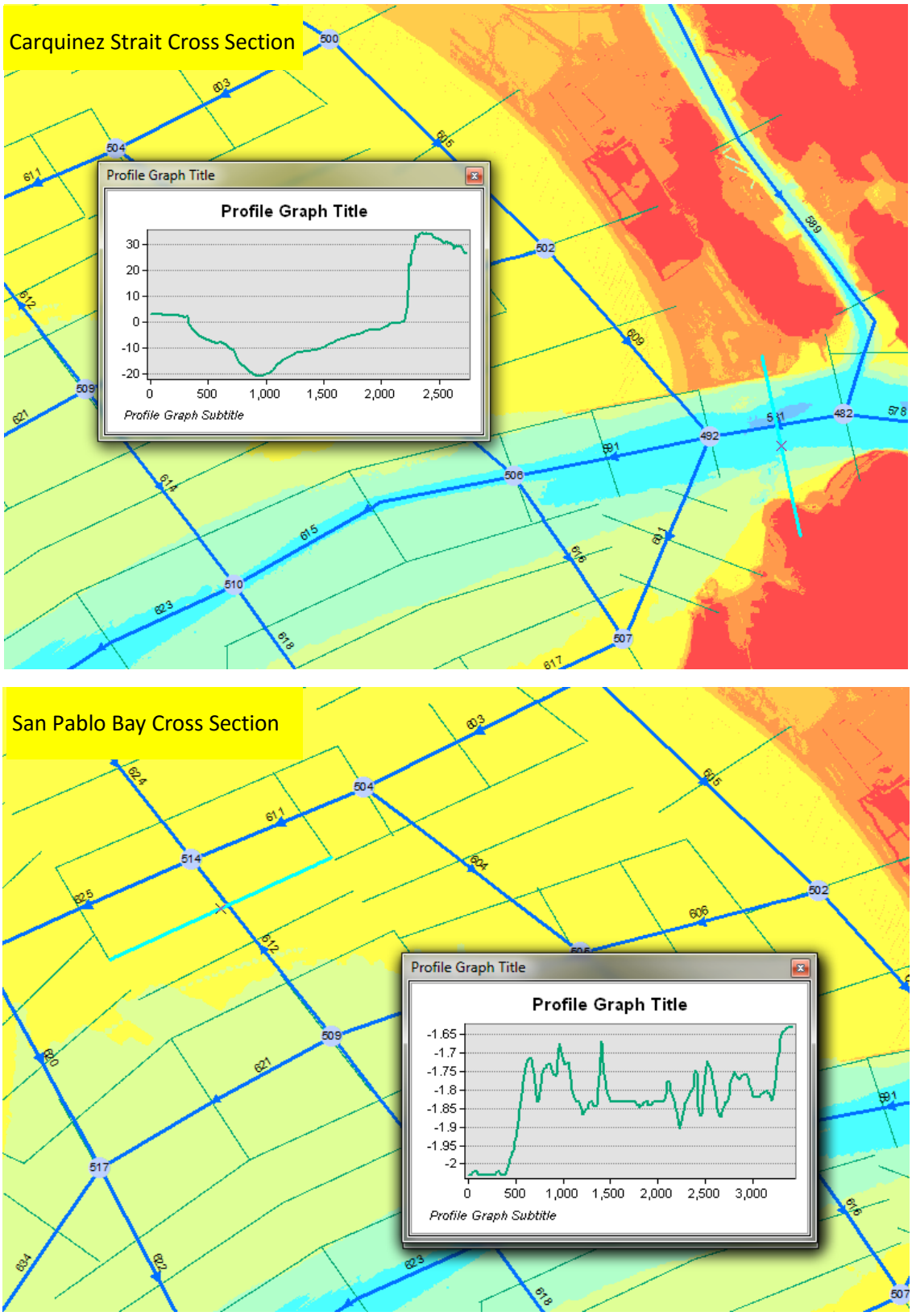


Figure 3-4 Extension Grid Highlighting Cross Sections and Computed Cross-section Profiles Coordinates

3.4.2 Channel Volume

The volume for each channel reach was calculated as the volume between the "channel top area" and the DEM underneath it. Figure 3-5 shows a portion of a "channelized" San Pablo Bay with a few "channel top areas," which are highlighted. This volume is then compared to an estimation of what DSM2 might "see" as volume for each channel, which is calculated as the average of two consecutive cross-sectional areas multiplied by the longitudinal distance between the cross sections. If the relative difference between these two values is greater than 10 percent, the channel length input in DSM2 is modified to maintain the relative difference within 10 percent, thereby keeping the channel reach volume in DSM2 close to the more accurate volume obtained through geoprocessing. Most of the channel length modifications occurred for cross channels, which are those channels that run transverse to the main flowlines parallel to the main channel (thalweg) and for "channel top areas," which diverge from a desired mostly rectangular shape, which is not always possible. Because the bays are not rectangular and because the polygons representing the "channel top areas" must tessellate (i.e., must fit together without gaps or overlap), not all "channel top areas" are rectangular.

3.4.3 Reservoir Surface Area and Bottom Elevation

Reservoir volumes are calculated in the same way as channel reach volumes are calculated. In DSM2, reservoirs are modeled as prisms, that is, uniform bottom elevation and constant surface area with depth. And so, fully defining a reservoir in DSM2 requires surface area and average bottom elevation. Once again, Arc GIS geoprocessing tools are used to calculate these values.

Reservoir connections to network nodes are calculated using the reservoir connection formulas.

$$Q = C_{to}\sqrt{2g(z_{node} - z_{res})}\ for\ z_{res} < z_{node}. \quad (1)$$

$$Q = C_{from}\sqrt{2g(z_{res} - z_{node})}\ for\ z_{res} > z_{node}. \quad (2)$$

Where

- C_{to} and C_{from} are coefficients representing the hydraulic efficiency of the reservoir connection and the nominal area perpendicular to flow, which are estimated through calibration,
- g is gravity,
- z_{res} and z_{node} are the water surface elevations at the reservoir and connecting node (see http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/reference/reservoir.html).

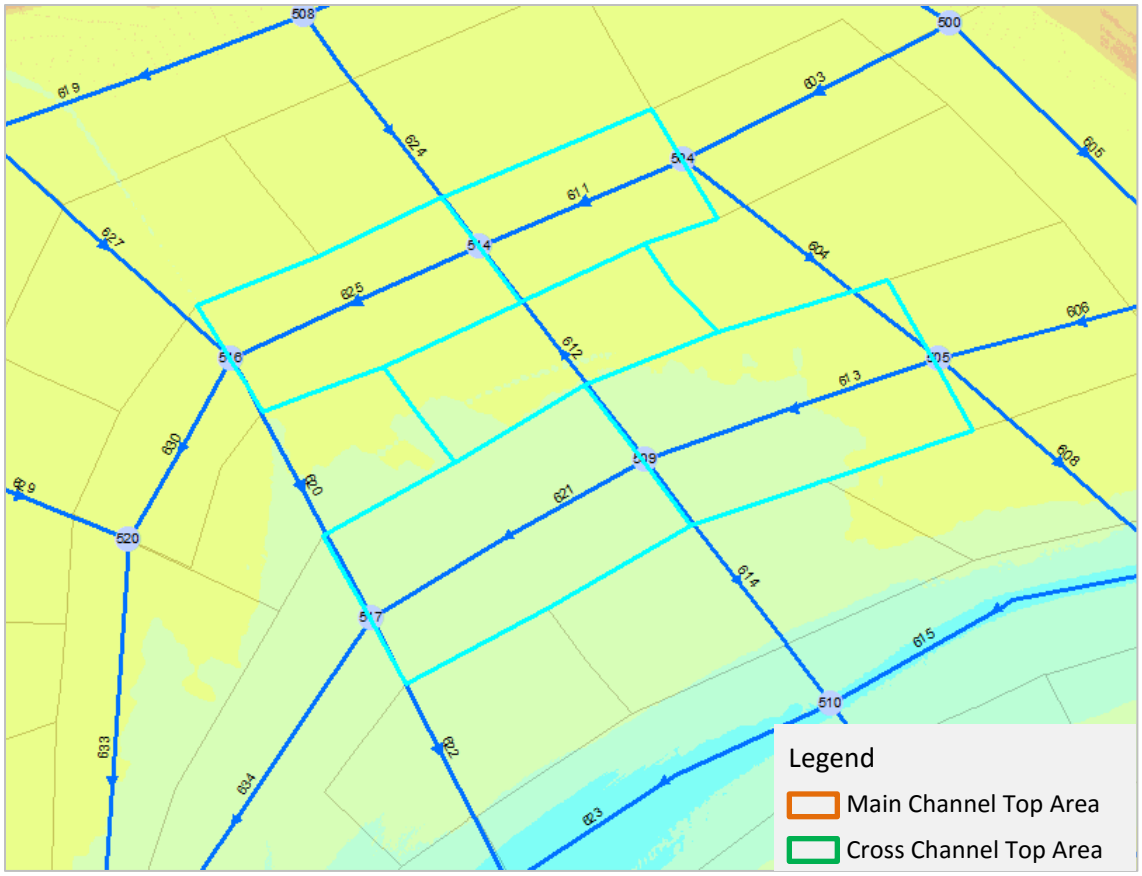


Figure 3-5 Detail of Extension Grid Highlighting "Channel Top Areas"

3.4.4 Calibration

In the first phase of this project, we attempted to translate the tide from the Golden Gate to Martinez. Accordingly, we worked with only the hydrodynamic module of DSM2, which is DSM2-Hydro. Once DSM2-Hydro successfully reproduces the stage at Martinez, we will calibrate the entire DSM2 model (both DSM2-Hydro and DSM2-Qual) to simulate both hydrodynamics and salt transport from the ocean to Martinez.

For DSM2-Hydro calibration, we focused on modifying Manning's n and reservoir coefficients. The procedure was completed using PEST, a parameter estimation software package (Doherty 2010). The DSM2 simulated stage at all extended grid nodes and reservoirs are compared to stage obtained from a historical model of the Bay-Delta by using SCHISM.

3.5 Preliminary Results and Next Steps

Results of a preliminary DSM2-Hydro calibration with PEST are encouraging. Figure 3-6 shows the comparison of stage at selected locations in the extended grid from the Golden Gate to Martinez and stage in the DSM2 reservoirs, which represent parts of San Francisco and San Pablo bays. DSM2 was run June 20, 2008–August 2, 2009. The SCHISM operation used to provide "observed" data was April 1, 2009–July 24, 2010. The calibration period was July 2009.

The charts in Figure 3-7 show a very good water-surface elevation match between SCHISM and Extended Grid Hydro (DSM2), particularly considering that we are in the initial stages of calibrating the extended grid model. The relatively small difference between SCHISM and the Extended Grid Hydro is encouraging, indicating that this approach might be viable.

To complete this first phase of this investigation, we will continue calibrating Hydro using PEST, perhaps extending the calibration period to more than one month.

The next stage of this investigation will be to calibrate the extended grid for DSM2-Hydro and DSM2-Qual, followed by a validation of the calibrated model.

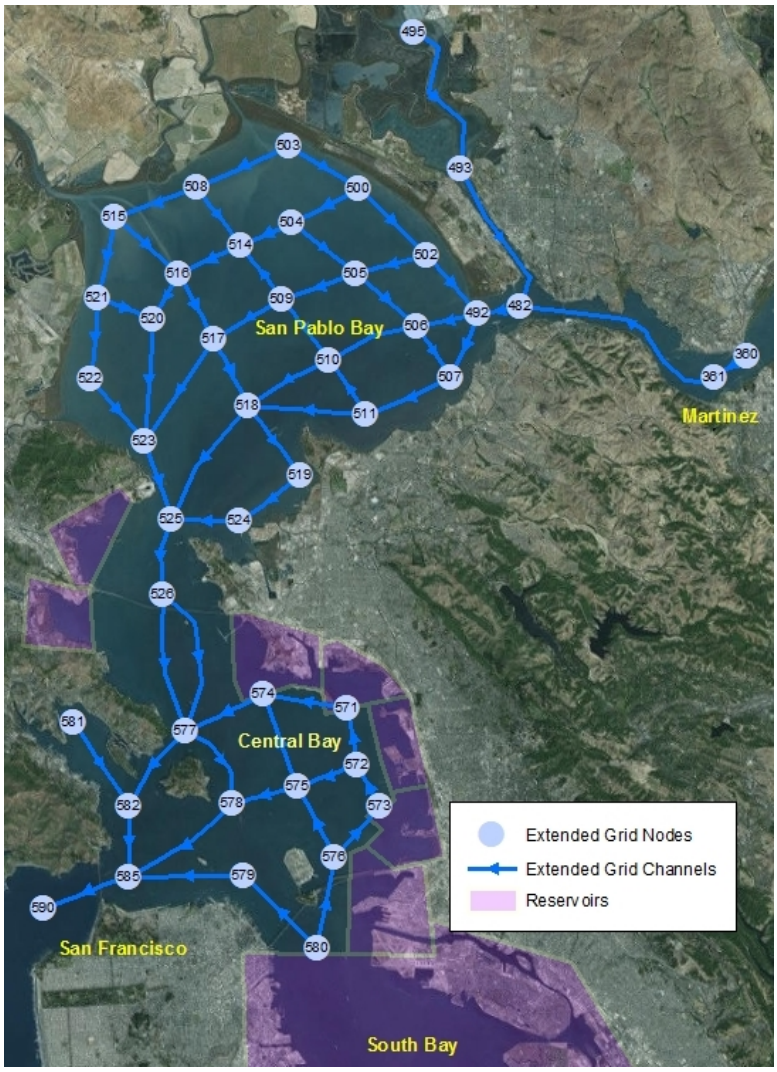
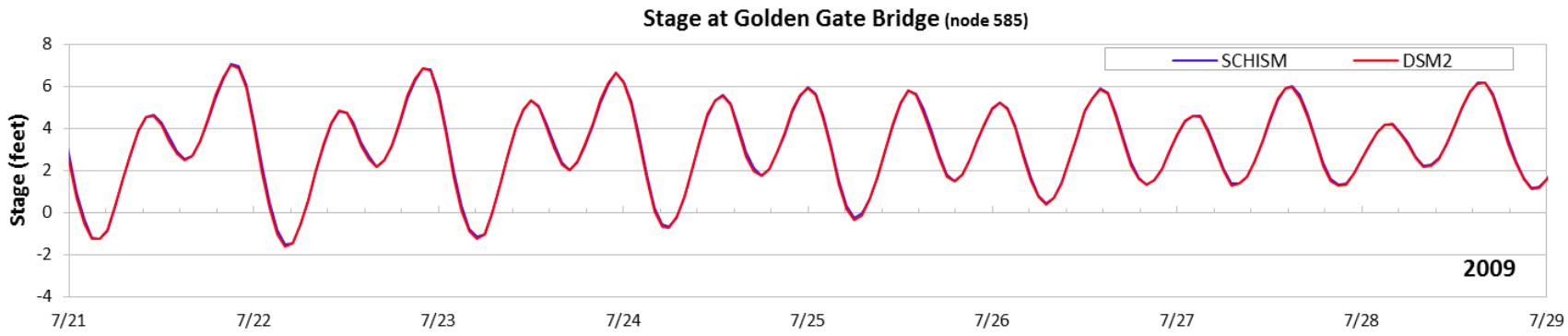
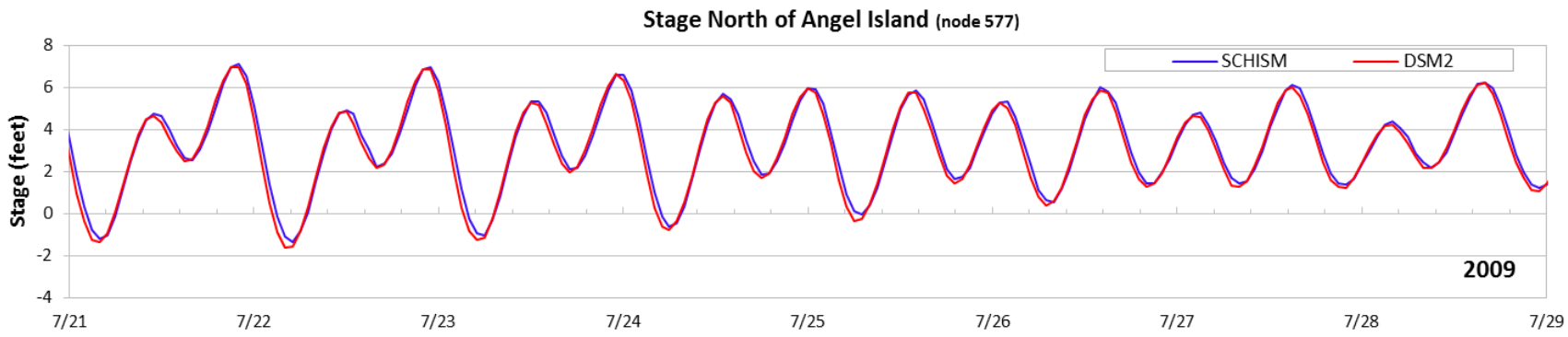
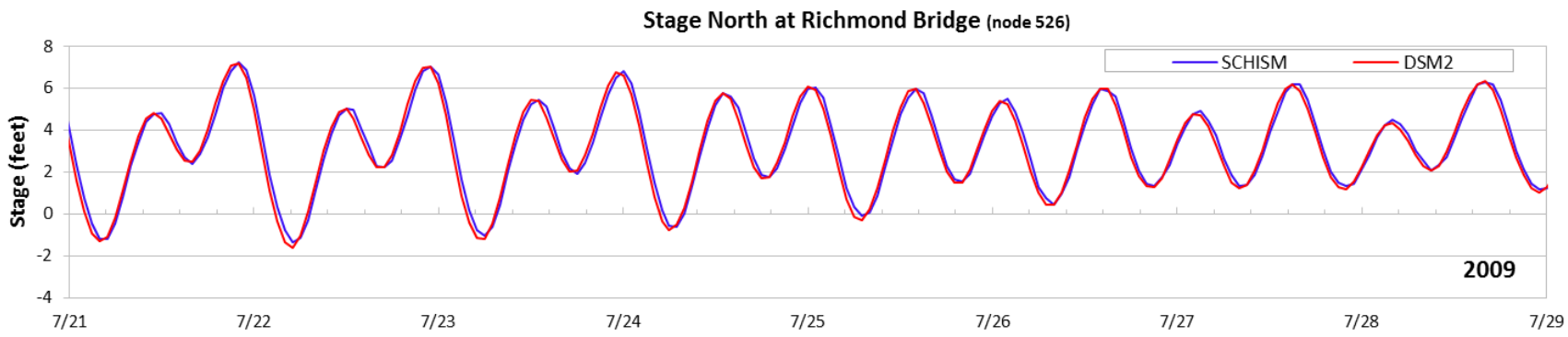
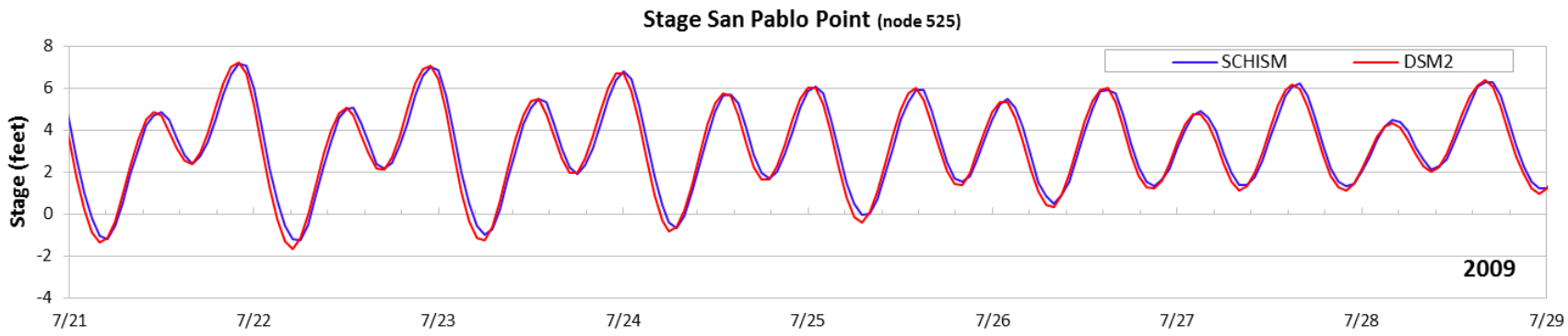


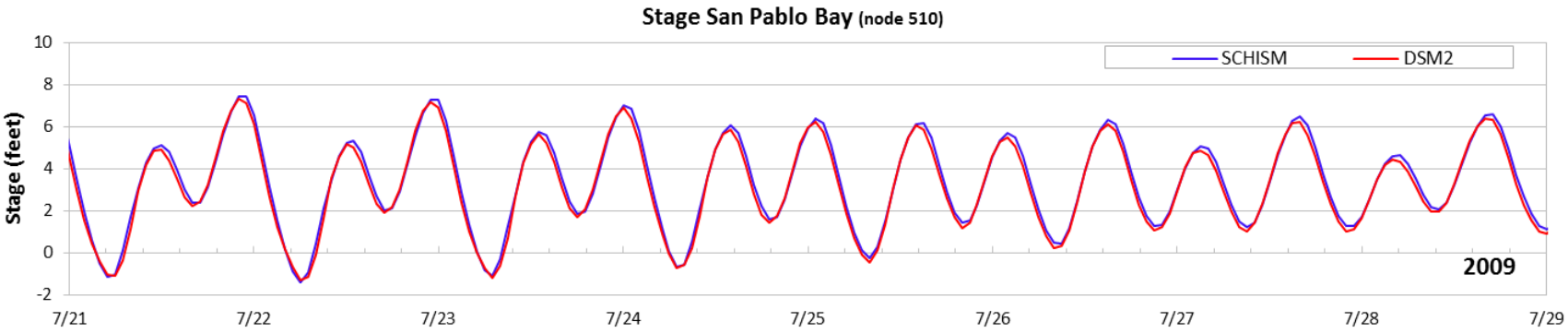
Figure 3-6 DSM2 Grid Extension Output Node Locations for Figure 3-7

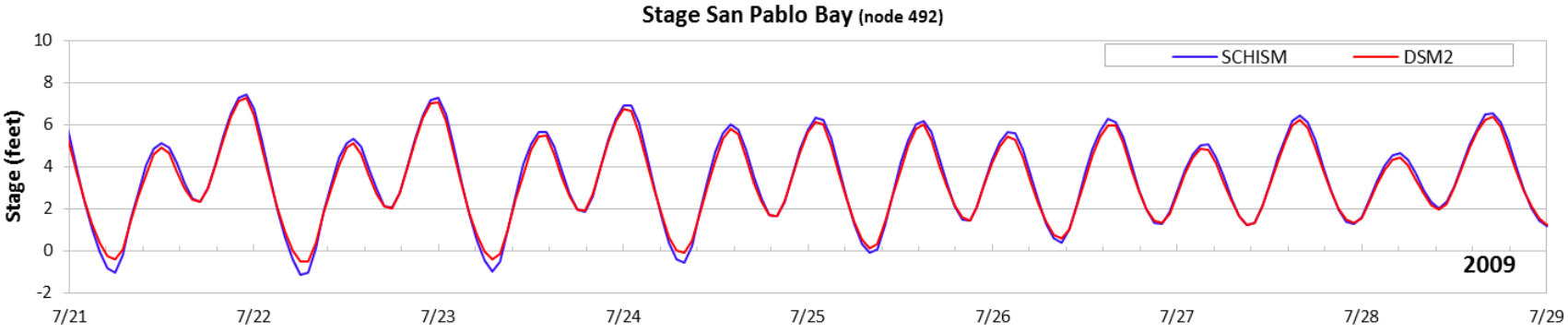

Stage at Golden Gate Bridge (node 585)
SCHISM
DSM2
Stage (feet)
8
6
4
2
0
-2
-4
2009
7/21
7/22
7/23
7/24
7/25
7/26
7/27
7/28
7/29

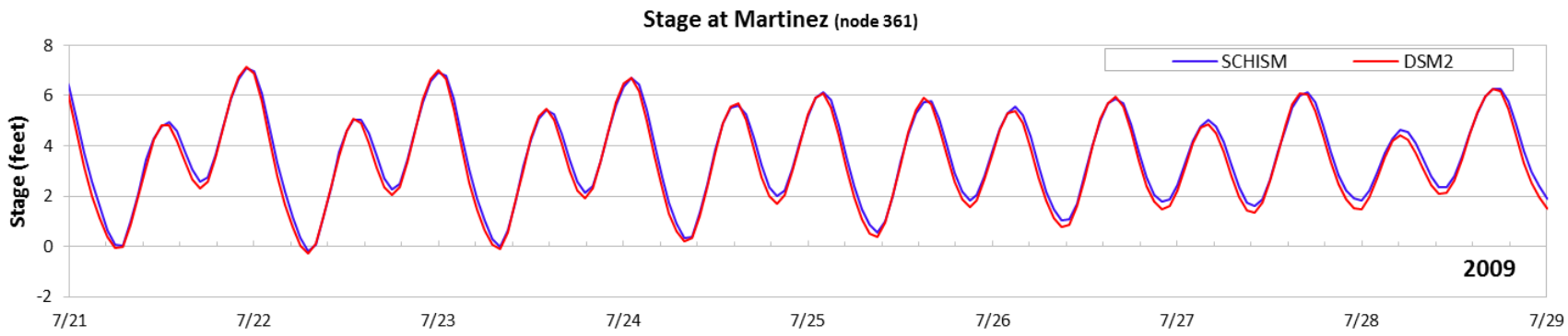

Stage North of Angel Island (node 577)
SCHISM
DSM2
Stage (feet)
8
6
4
2
0
-2
-4
2009
7/21
7/22
7/23
7/24
7/25
7/26
7/27
7/28
7/29

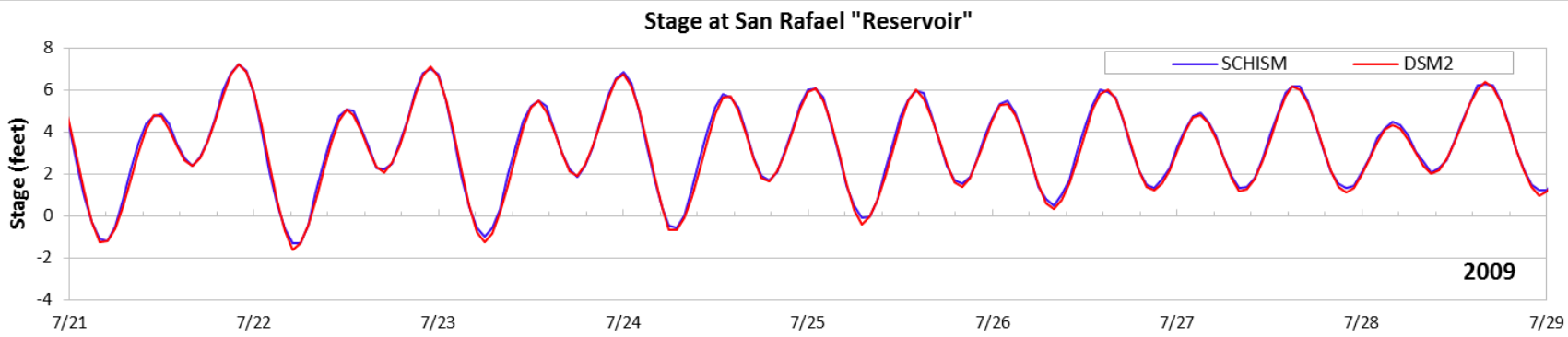

Stage North at Richmond Bridge (node 526)
SCHISM
DSM2
Stage (feet)
8
6
4
2
0
-2
-4
2009
7/21
7/22
7/23
7/24
7/25
7/26
7/27
7/28
7/29

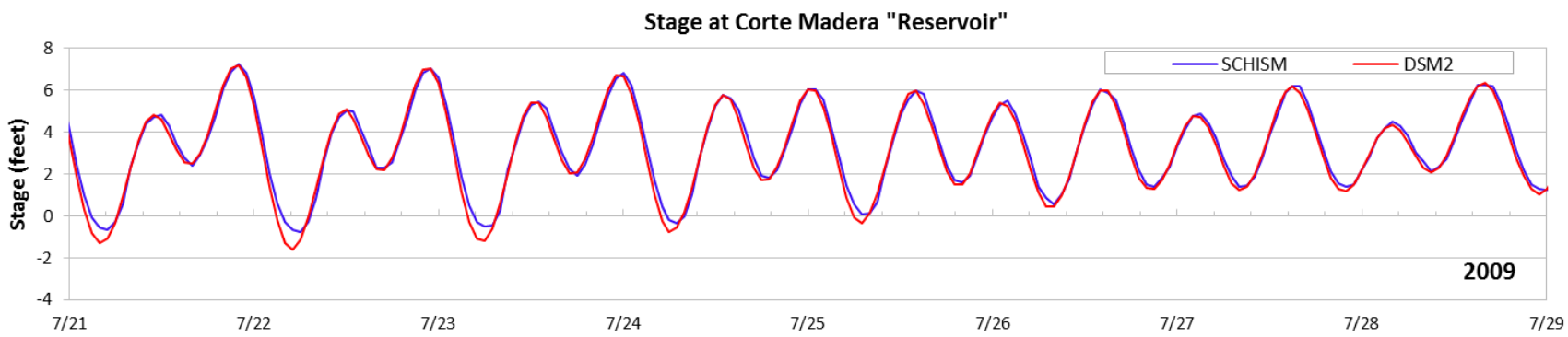

Stage San Pablo Point (node 525)
SCHISM
DSM2
Stage (feet)
8
6
4
2
0
-2
-4
2009
7/21
7/22
7/23
7/24
7/25
7/26
7/27
7/28
7/29

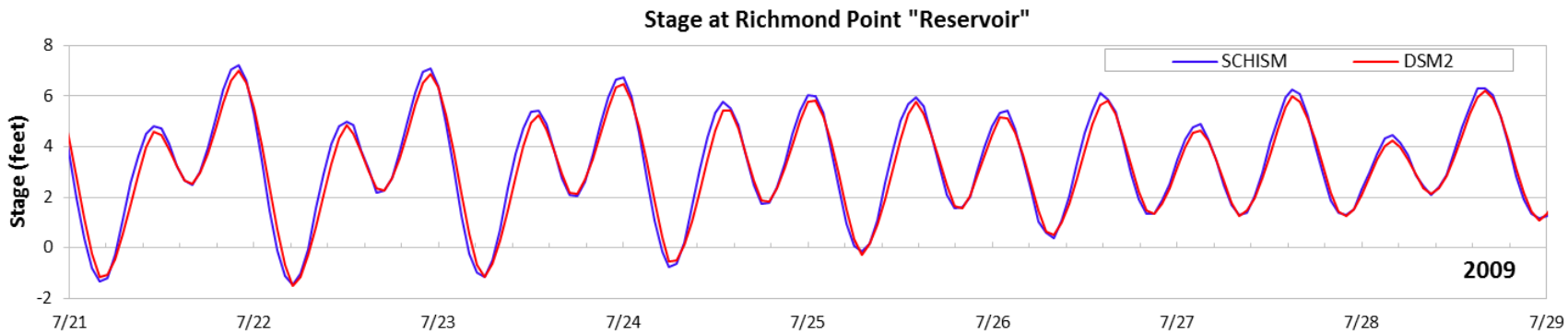

Stage San Pablo Bay (node 510)
SCHISM
DSM2
Stage (feet)
10
8
6
4
2
0
-2
2009
7/21
7/22
7/23
7/24
7/25
7/26
7/27
7/28
7/29

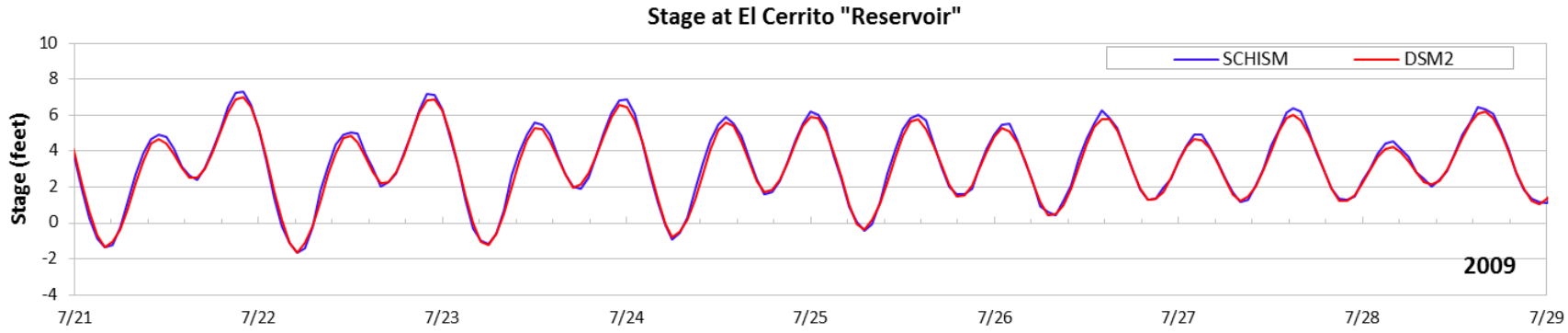

Stage San Pablo Bay (node 492)
SCHISM
DSM2
Stage (feet)
10
8
6
4
2
0
-2
2009
7/21
7/22
7/23
7/24
7/25
7/26
7/27
7/28
7/29

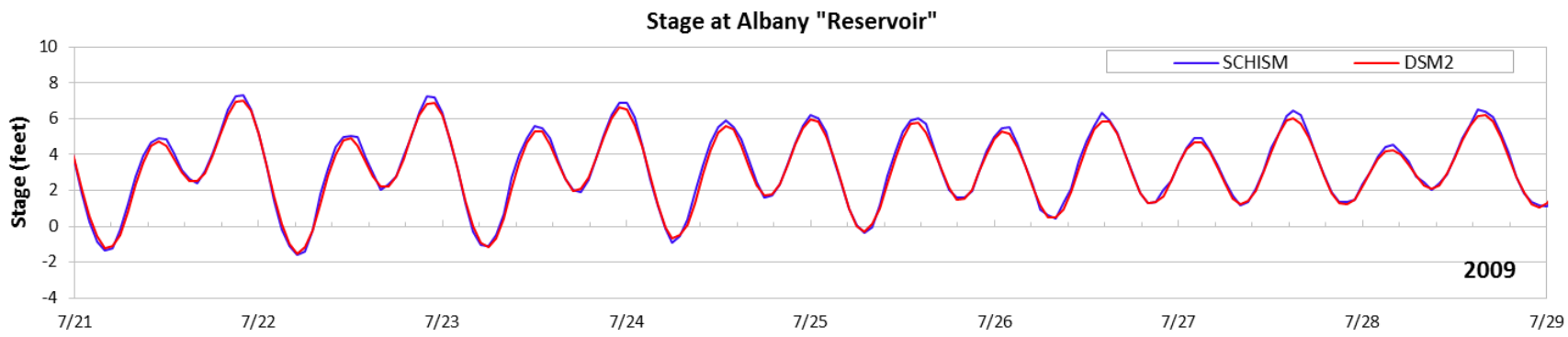

Stage at Martinez (node 361)
SCHISM
DSM2
Stage (feet)
8
6
4
2
0
-2
2009
7/21
7/22
7/23
7/24
7/25
7/26
7/27
7/28
7/29


Stage at San Rafael "Reservoir"
SCHISM
DSM2
Stage (feet)
8
6
4
2
0
-2
-4
2009
7/21
7/22
7/23
7/24
7/25
7/26
7/27
7/28
7/29


Stage at Corte Madera "Reservoir"
SCHISM
DSM2
Stage (feet)
8
6
4
2
0
-2
-4
2009
7/21
7/22
7/23
7/24
7/25
7/26
7/27
7/28
7/29


Stage at Richmond Point "Reservoir"
SCHISM
DSM2
Stage (feet)
8
6
4
2
0
-2
2009
7/21
7/22
7/23
7/24
7/25
7/26
7/27
7/28
7/29


Stage at El Cerrito "Reservoir"
SCHISM
DSM2
Stage (feet)
10
8
6
4
2
0
-2
-4
2009
7/21
7/22
7/23
7/24
7/25
7/26
7/27
7/28
7/29


Stage at Albany "Reservoir"
SCHISM
DSM2
Stage (feet)
10
8
6
4
2
0
-2
-4
2009
7/21
7/22
7/23
7/24
7/25
7/26
7/27
7/28
7/29

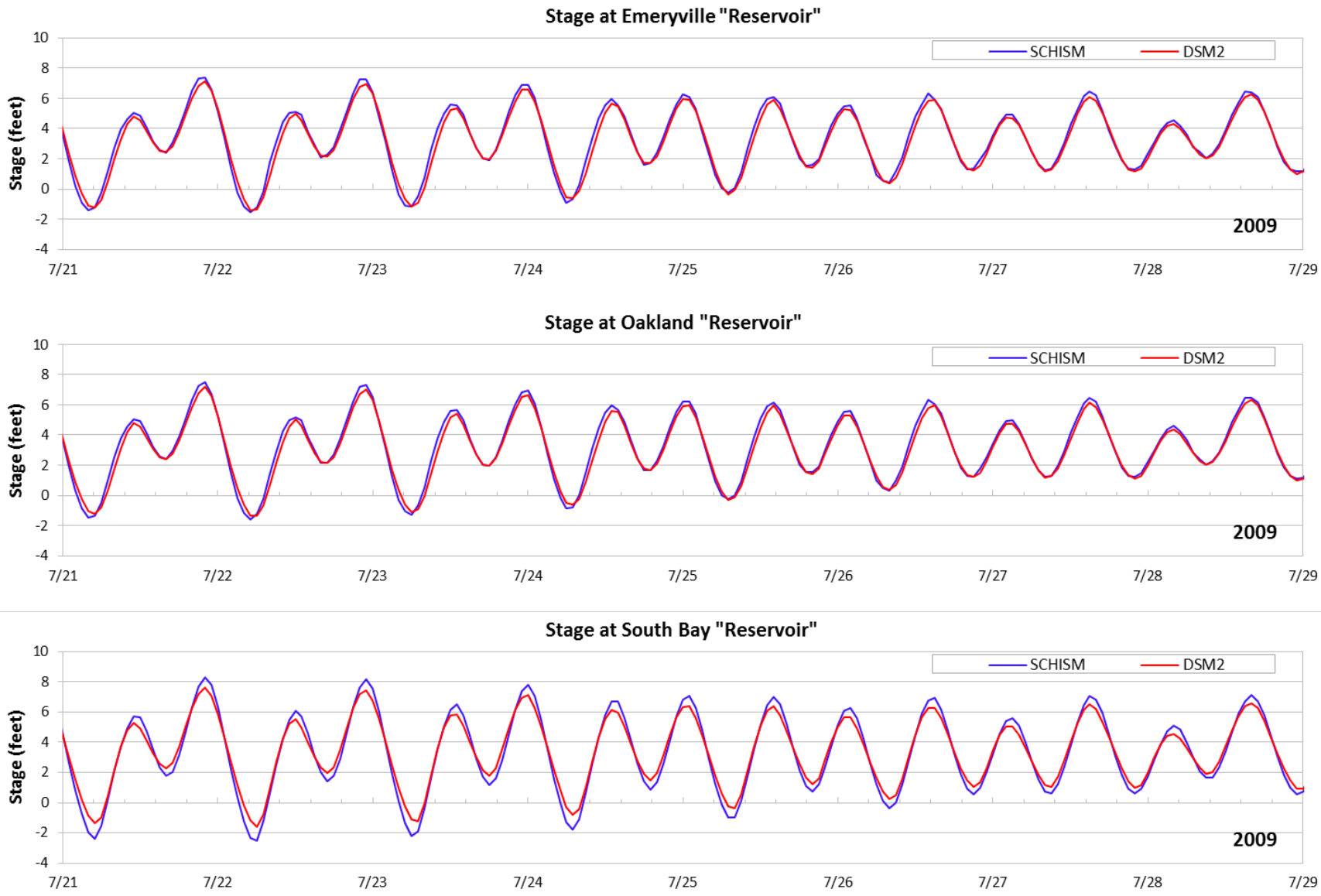


Figure 3-7 Stage Comparison at Different Locations in Extended Grid

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