9. Hands On: Salinity

Case for Jupiter Inlet, FL

Salinity refers to the salt content of water. Its value runs typically from 0 for fresh water to 31-35 ppt (parts per thousand) for ocean water. In water bodies with poor mixing and limited water exchange, or experiencing high evaporation, salinity can be higher and lead to formation of brine. Table 9.1, taken from the Wikipedia, presents typical values and nomenclature for describing degree of saline water:

Table 9.1. Water salinity.

Fresh water	Brackish water	Saline water	Brine
< 0.05 %	0.05 – 3 %	3 – 5 %	> 5 %
< 0.5 ppt	0.5 – 30 ppt	30 – 50 ppt	> 50 ppt

In coastal zones and estuaries, both temporal and spatial variations in salinity are controlled by changes in circulation, waves, tides, precipitation, evaporation, and freshwater inflows. These changes in salinity can have major effects on water density and water stratification to modify circulation patterns. Dynamic behavior of suspended sediment can be controlled by the salinity-driven flow and mixing. Any sustained changes to salinity can directly change the aggregation and consolidation of cohesive sediment as well (Nicholson and O'Connor 1986). Salinity can also alter the water chemistry that is closely related to marine organisms. Distribution and abundance of marine life will change water turbidity and define water quality in coastal and estuarine systems. Modifications of coastal inlets, such as channel deepening and widening and rehabilitation or extension of jetties may alter the salinity distribution within the estuary.

CMS-Flow is presently capable of 2D salinity computations. The simulation of salinity can often require a 3D solution due to the presence of vertical salinity gradients that can significantly influence the flow. It is therefore important to understand the limitations of 2D salinity simulations, and apply them only when the assumptions inherent in 2D simulations are valid. Typically, validity of 2D salinity implies strong mixing through the water column. These well mixed conditions are usually met for shallow bays with open exchanges to the ocean or gulf, and strong tidal signals and sufficient wind energy to provide the vertical mixing. Also, the assumption of sufficient energy to mix over the water column is valid under storm conditions, even for deeper water bodies. Finally, when the exchange with the open sea is restricted by an inlet, the tidal range is an important indicator of vertical mixing conditions. For low tide ranges, significant vertical stratification can occur, even in shallow bays and estuaries, especially when the winds are calm. Pritchard (1955) and Cameron and Pritchard (1963) have classified estuaries using stratification and salinity distribution as the governing criteria, and these classifications can be used for guidance in applying the 2D simulations.

To calculate salinity transport, you will need the regular hydrodynamic input files. In this section, the salinity modeling is described to demonstrate the CMS capability in the Jupiter Inlet - Loxahatchee River, FL. This system is shallow and well-mixed, thus a 2D model can be applied to evaluate salinity. The salinity calculations are compared to measurements at two monitoring stations.

The Loxahatchee River is a 7.6-mile-long river near the southeast coast of Florida. Freshwater meanders through the river's three main forks, the North Fork, the Northwest Fork and the Southwest Fork, into the brackish estuary and then flows out Jupiter Inlet into the Atlantic Ocean (Figure 9.1). The estuary entrance is protected by dual jetties from ocean waves. Momentum transfer, diffusive process and spatial distributions of salinity in the Jupiter Inlet-Loxahatchee River system are dominated by tides, wind, and freshwater inflows.

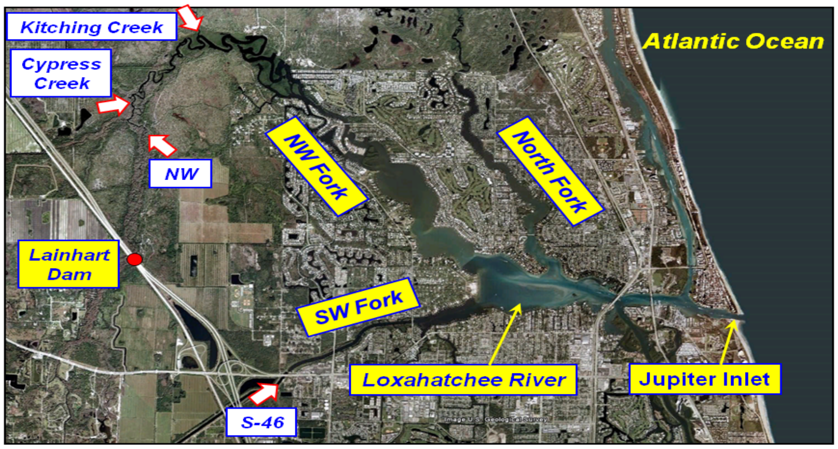


Figure 9.1. The Jupiter Inlet - Loxahatchee River System, FL. Arrows are designated for freshwater inflow locations.

In application of the CMS to the Loxahatchee River, a quadtree grid system was developed to discretize the bay and the offshore. The computational domain extends approximately 11.0 km alongshore and 4.5 km offshore, and the seaward boundary of the domain reaches to the 20 m isobath. Figure 9.2 shows the quadtree grid with 50,000 ocean cells and bathymetric features of the Jupiter Inlet-Loxahatchee River system and adjoining nearshore area. The CMS grid permits fine resolution in areas of high interest such as jetties, channels, the bay, and the river. The implicit solver of the CMS with a large time step of 10 minutes was employed for the simulation. Comparing to the explicit solver for a similar model, the computation time was reduced by more than 50%.

River and estuarine survey data were obtained from U. S. Geological Survey (USGS), the Loxahatchee River District (LRD), and U. S. Coastal Guard (USCG). Arrows and red dots in Figures 9.1 and 9.2 indicate the station locations where freshwater inflows, water surface elevation, and salinity data were collected. Daily freshwater flows are available at four USGS gages, Lainhart Dam (NW), Cypress Creek, Kitching Creek, and S-46 (Figure 9.1). USGS also monitors tide and salinity at the Trapper Nelson's Interpretive Site (WL Station) and Boy Scout Camp dock (Station B) (Figure 9.2). Salinity data near the mouth of Kitching Creek (Station A) were collected by the LRD. Both salinity and tide were measured near Jupiter Inlet at the USCG Station.

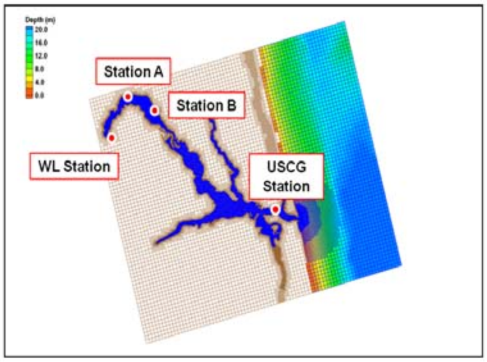


Figure 9.2. CMS domain, quadtree grid, bathymetry. Red dots are designated for the river and estuarine survey stations.

CMS-Flow is driven by time-dependent water surface elevation at the offshore and intracoastal open boundaries, wind forcing over the surface boundary, and freshwater inflows from rivers and tributaries. Time varying salinity values are specified along the open ocean boundaries and the river boundaries with the freshwater inflows (Figure 9.1). The initial salinity field is specified for the entire CMS domain as well.

The CMS hydrodynamic input files for the Jupiter Inlet-Loxahatchee River system, FL are required and prepared within the SMS shown in Figure 9.3:

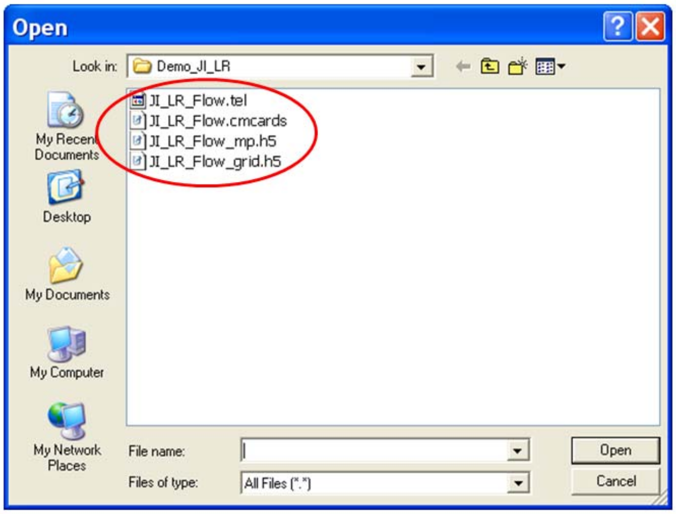


Figure 9.3. Files for the CMS-Flow salinity simulation.

- Setting up the Salinity Calculation

    1. *Open*  the JI_LR_Flow.cmcards file, located under *Demo_JI_LR*, in the SMS,

    2. Choose *CMS-Flow* | *Model Control*,

    3. Click on *Salinity*, and select *Calculate salinity* (Figure 9.4),

    4. Specify *Transport rate* under *Time steps* as 600 sec (equal to the hydrodynamic time step) for the salinity calculation.

Because of the large salinity range in a coastal system, model calculations can require long spin-up periods for a salinity simulation to reach the present salinity distribution, which could range from a few days to weeks. To shorten the spin-up time, an accurate initial condition for the salinity field should be specified. There are two options to assign the initial salinity condition in CMS-Flow:

- A Global Initial Salinity

    1. Check *Global concentration (ppt)* under *Initial condition* (Figure 9.4),

    2. Specify a constant initial value for the entire model domain.

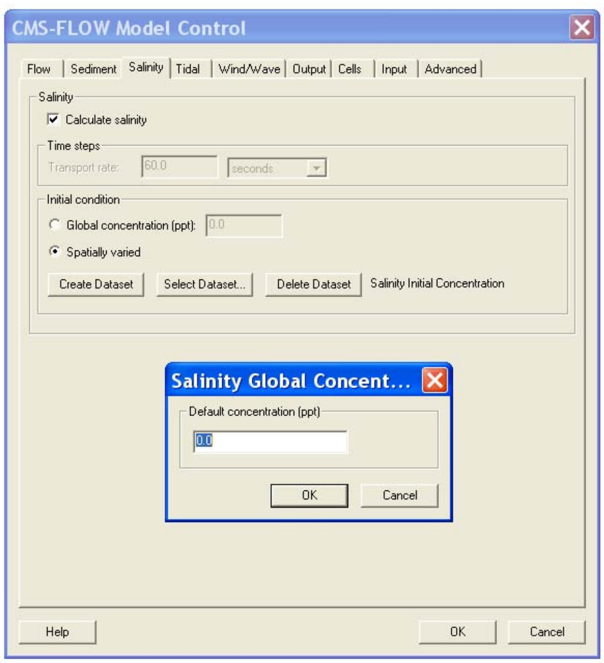


Figure 9.4. Setting up the salinity calculation and specifying spatially varied initial salinity.

- Spatially Varying Initial Salinity

  1. Choose the *Spatially varied* toggle under *Initial condition* (Figure 9.4),

  2. Click *Create Dataset* and assign a value under *Default concentration (ppt)* in the pop-up window. This step will generate a new dataset with a constant initial salinity value,

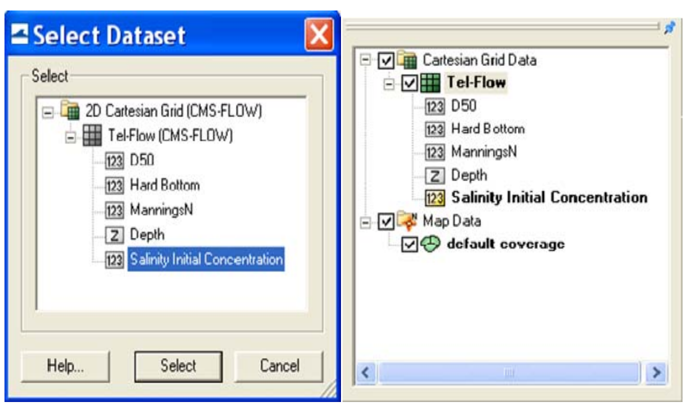
  3. Click *Select Dataset* under *Spatially varied* for an existing dataset and then select the dataset for the initial salinity that already exists (Figure 9.5a).

  4. Click *OK* to close this window and then click *OK* to close the *CMS-FLOW Model Control* window,

  5. Highlight the dataset, *Salinity Initial Concentration*, in the CMS-Flow data tree as appeared in Figure 9.5b,

  6. Specify different salinity values in the CMS domain in the same way to modify other datasets such as *D50* or *Hard Bottom*.

The dataset for a spatially varying initial salinity can also be generated by using the *Data Calculator* tool in the *Data* menu (Demirbilek et al. 2008).



(a) **(b)**

Figure 9.5. CMS-Flow data tree.

Based on the historical survey data, initial salinity is assigned in the dataset, *Salinity Initial Concentration*, for the Jupiter Inlet-Loxahatchee River system. The salinity varies from 1.0 ppt at the upstream of the river to 32.0 ppt at the offshore and intracoastal open boundaries (Figure 9.6).

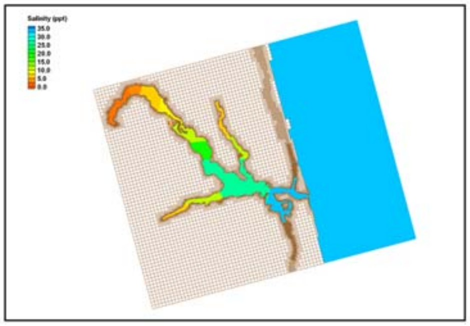


Figure 9.6. Initial salinity distribution.

To calculate salinity transport, salinity values at CMS-Flow boundaries need to be specified. Two salinity boundary types are available in the CMS: water surface elevation (WSE) boundary (*WSE-forcing* boundary) (Figure 9.7a) and freshwater inflow boundary (*Flow rate-forcing* boundary) (Figure 9.7b).

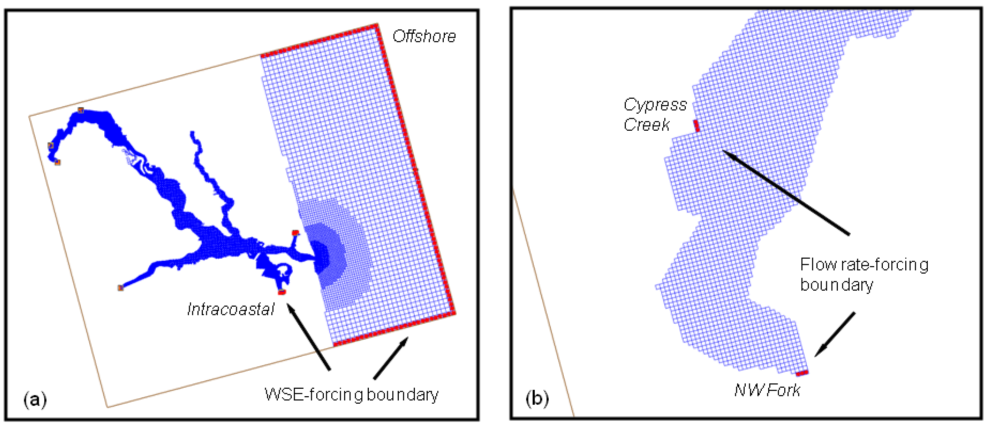
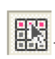


Figure 9.7. Salinity boundary types in the CMS.

- *WSE-forcing* Boundary

1. Select the *Cellstring*  tool and click/highlight the cellstring of water surface elevation boundary as shown in Figure 9.7a,

2. Select *CMS-Flow* | *Assign BC* to open the *CMS-Flow Boundary Conditions* window (Figure 9.8),

3. Click *Curve undefined* under *Salinity* on the left hand side of the dialog,

4. Click the *Import* button to read a salinity boundary input file in xys format (Figure 9.9) (Aquaveo 2010) or manually enter time and salinity values in two separate data columns or import salinity data from an opened *Excel* file by *Copy/Paste*.

The salinity and water surface elevation measurements at the USCG Station were assigned to the offshore and intracoastal open boundaries. The 31-day time series of salinity data (December 2002) is shown for the *WSE-forcing* boundary in Figure 9.9. Salinity at this location varies between 28.5 and 36.0 ppt and shows influence of the ocean during the period.

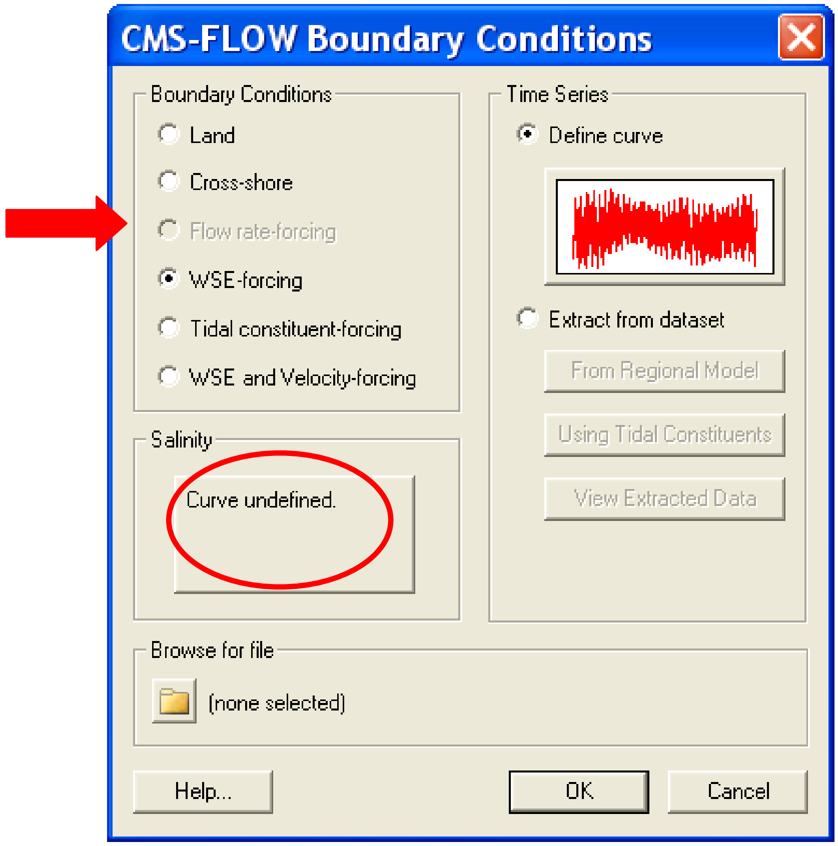


Figure 9.8. Salinity specifications along the *WSE-forcing* boundary.

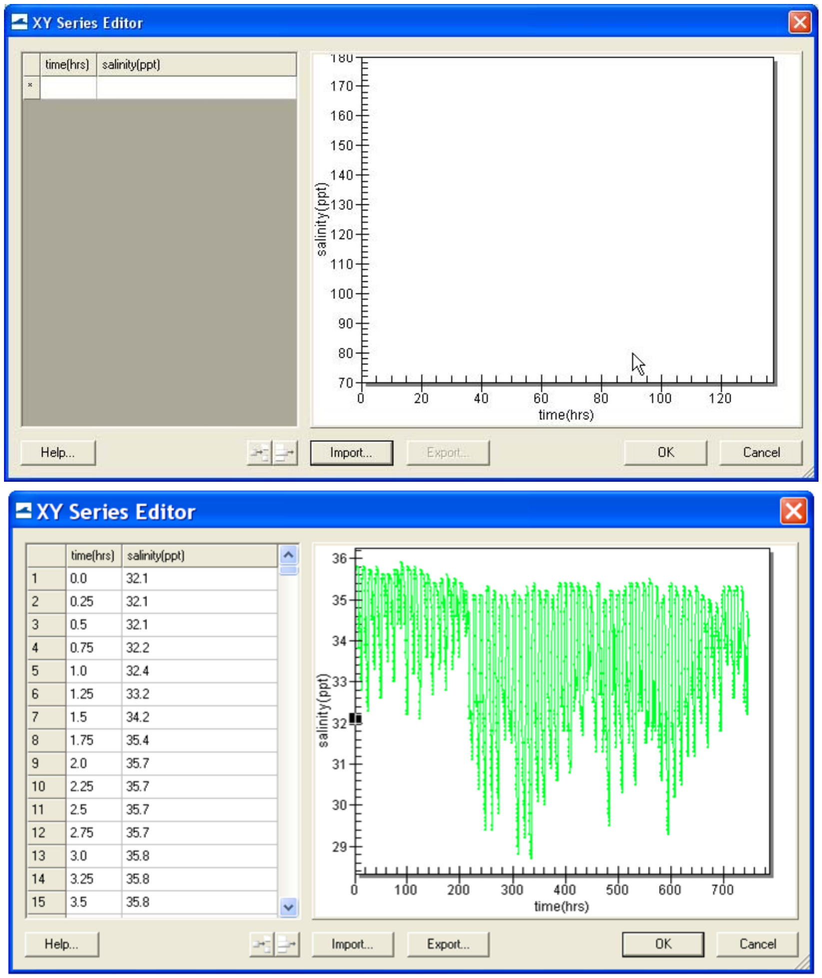


Figure 9.9. Salinity boundary input from a xys file.

- *Flow rate-forcing* Boundary

Following the same steps as specifying the *WSE-forcing* boundary, salinity values at freshwater inflow boundaries can be assigned together with flow specifications.

1. Select the *Cellstring* tool and click/highlight the cellstring of flow boundary as shown in Figure 9.7b,

2. Select *CMS-Flow* | *Assign BC* to open the *CMS-Flow Boundary Conditions* window (Figure 9.10),

3. Click *Salinity* on the left hand side of the dialog,

4. Click the *Import* button to read a salinity boundary input file in xys format or manually enter time and salinity values in two separate data columns or import salinity data from an opened *Excel* file by *Copy/Paste*.

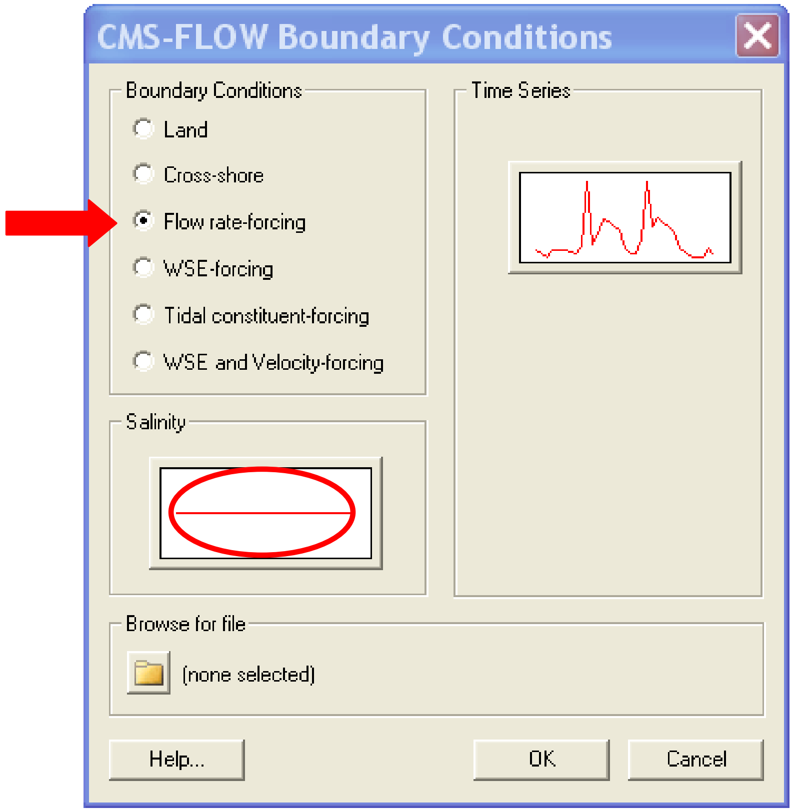


Figure 9.10. Salinity specifications along the *Flow rate-forcing* boundary.

A few rivers and creeks flow into the Jupiter Inlet - Loxahatchee River system and flow measurements are available at four USGS gages. A zero salinity value is assigned at the *Flow rate-forcing* boundaries.

- Loading salinity solution file

Once selecting the salinity calculations, you will need to update the *Output* options in *CMS-Flow | Model Control* for your solution file. The CMS-Flow simulation with salinity transport will generate an extra scalar data subset within the hydrodynamic solution file, *Salinity*, in a typical CMS-Flow solution data tree (Figure 9.11).

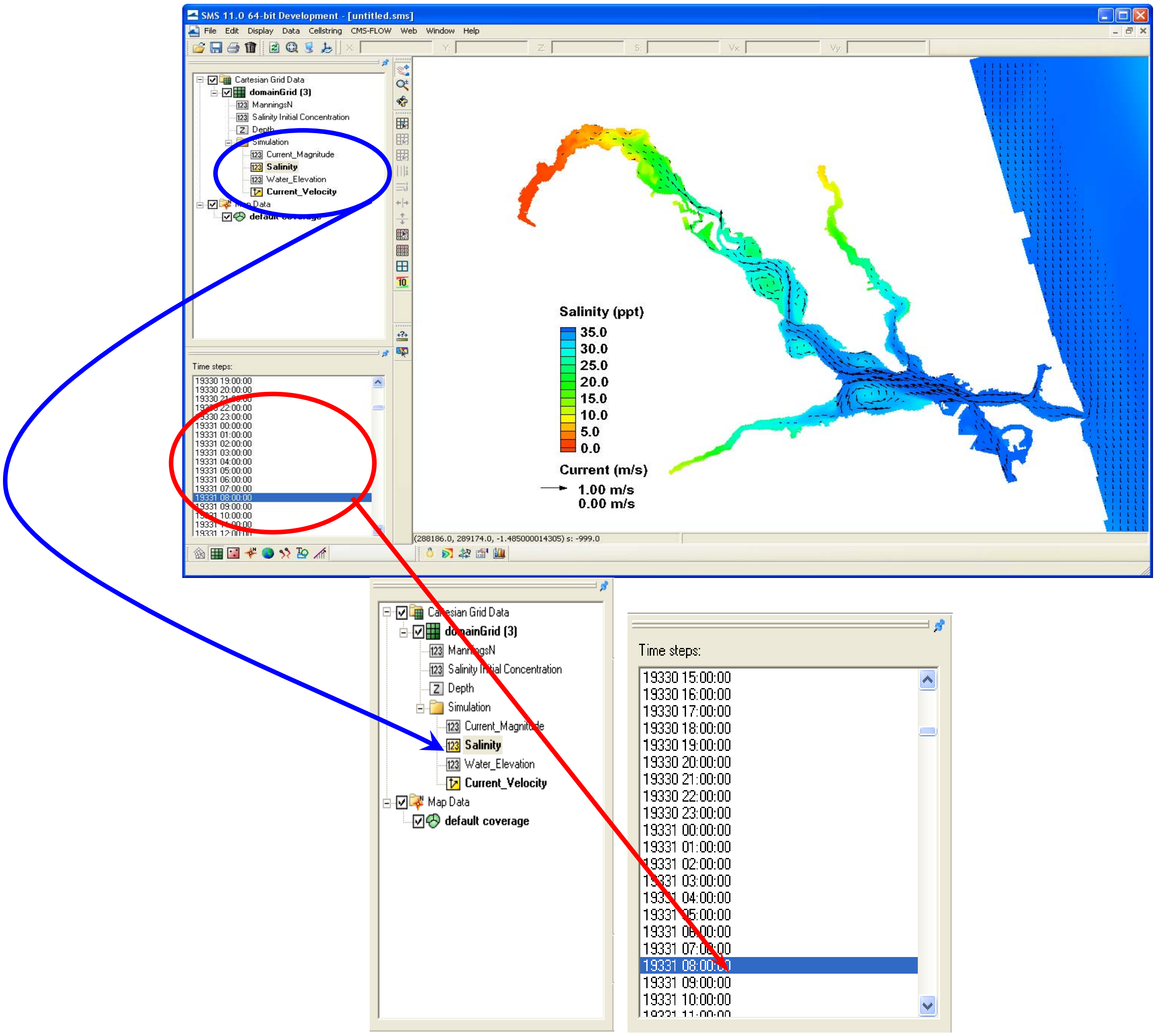


Figure 9.11. Salinity calculations in the Jupiter Inlet – Loxahatchee River system.

1. Choose *File* | *Open*,
2. Browse your folders to find the solution file, JI_LR_Flow_sol.h5, in the Demo_JI_LR folder,
3. Press *Open*.

- Displaying salinity distribution (Figure 9.12)

1. Click/highlight the salinity output, Salinity, under the *Simulation* in the *Cartesian Grid Data* tree,
2. Choose *Display* | *Display Options*,

3. Click *Cartesian Grid* on the left hand side of the dialog,
4. Check *Contours* on the right hand side of the dialog,
5. Select the *Contours* button at the top of dialog,
6. Choose *Contour Method* | *Color Fill*,
7. Click the *Color Ramp* button to adjust the color scheme,
8. Set the proper salinity range by checking *Specify a range* (0-35 ppt),
9. Change *Contour Interval* to 15, plotting salinity contours every 2.5 ppt,
10. Click *OK* to exit *Display Options*.

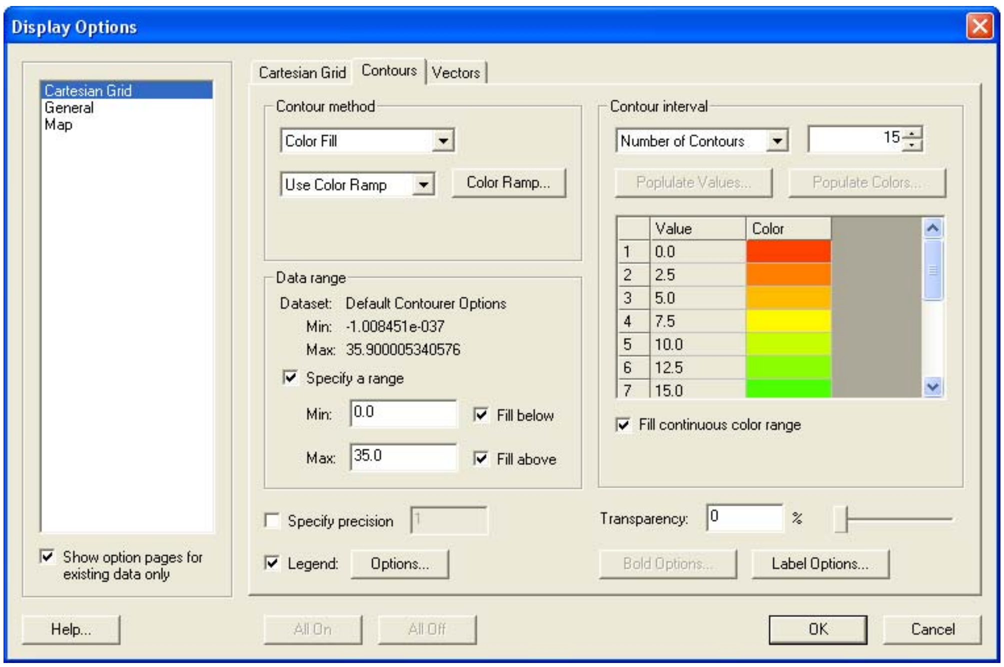


Figure 9.12. Setting up salinity display in *Display Options*.

For the Jupiter Inlet - Loxahatchee River system, the CMS-Flow simulation was conducted for December 2002. Depth-averaged current and salinity fields in the estuary and river were retrieved from two snapshots of the CMS results, corresponding to the flood and ebb currents, respectively (Figure 9.13).

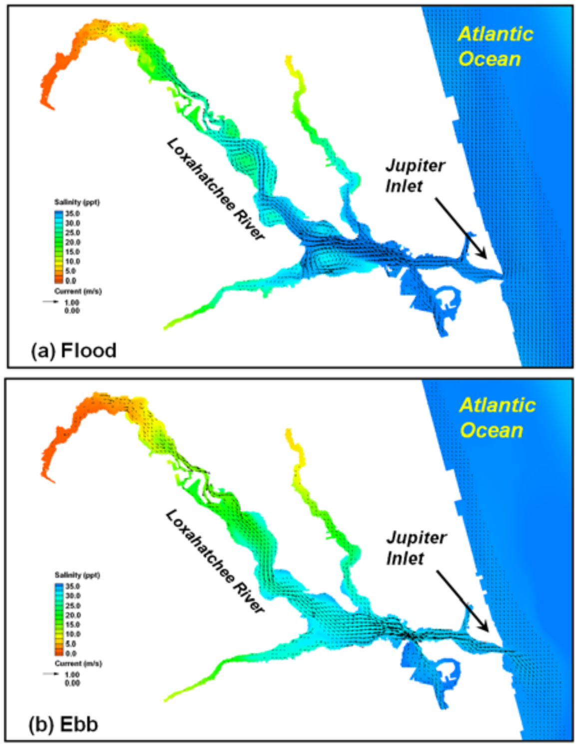


Figure 9.13. Salinity and current distributions during (a) the flood current and (b) the ebb current.

The current speed is more than 1.0 m/sec at the embayment during the flood and ebb tides. The downstream reach of the Loxahatchee River is dominated by relatively high salinity ocean water during the flood tide (> 34.0 ppt) and low salinity water fills the bay during the ebb tide (< 28.0 ppt). A salt front in the NW Fork of the river indicates the interaction of freshwater plume and ocean water intrusion. The front can be pushed to the upstream end of the NW Fork by a strong flood current passing Boy Scout Camp dock (Station B, Figure 9.2) and typically retreats into the embayment during the ebb tidal cycle.

Model configuration and model performance were examined by comparing the measured and computed water surface elevations at the Trapper Nelson's Interpretive Site (WL Station, Figure 9.2). Salinity calculations in the system were compared to data collected at Stations A and B (Figure 9.2).

Water surface elevation comparisons are shown in Figure 9.14. The calculated tide at this upstream river location has a good agreement with the measurements both in amplitude and phase. The correlation coefficient between the CMS and the data is 0.83 and the root mean square error (RMSE) is 0.15 m.

Figure 9.15 shows the salinity comparisons at Stations A and B. Significant salt intrusion by the flood tide can be seen at both locations. Salinity at Station B shows a much larger variability, from below 5 up to 25 ppt during this simulation period. To avoid the sensor exposure to air, salinity data at each monitoring station were collected at a water depth below the local mean lower low water (SFWMD 2005), which partially explains the discrepancy of salinity ranges between the data and the depth-averaged CMS results. A mid-depth gage measurement would likely be more closely comparable to the CMS calculations. In addition, insufficient representation of freshwater inflows, such as tributaries, surface runoffs, and groundwater, in the CMS could also result in smaller salinity variations. Correlation coefficients between the CMS and the data are 0.69 and 0.80, the root mean square errors (RMSE) are 1.11 and 4.00 ppt, and the relative RMSEs (RMSE/salinity range) are 11 and 16%, respectively at Stations A and B.

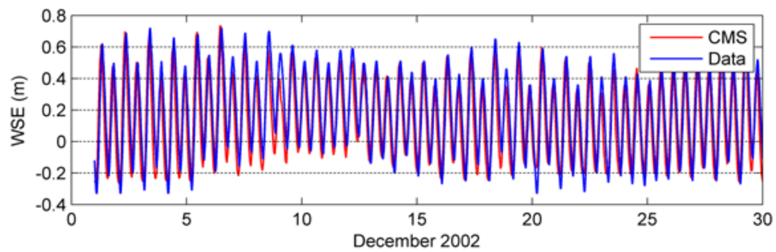


Figure 9.14. Calculated and measured water surface elevations at the Trapper Nelson's Interpretive Site for December 2002.

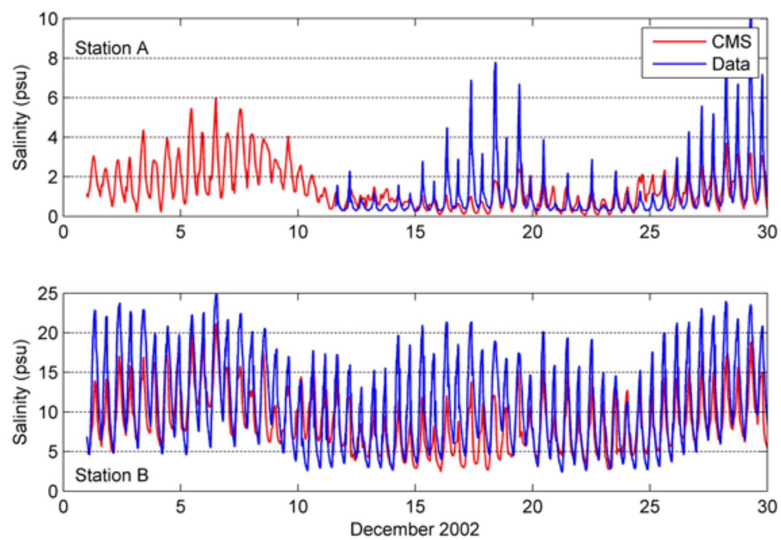


Figure 9.15. Calculated and measured salinity at Stations A and B for December 2002.