Simulating Salt Intrusion into Suisun Bay and the Western Delta

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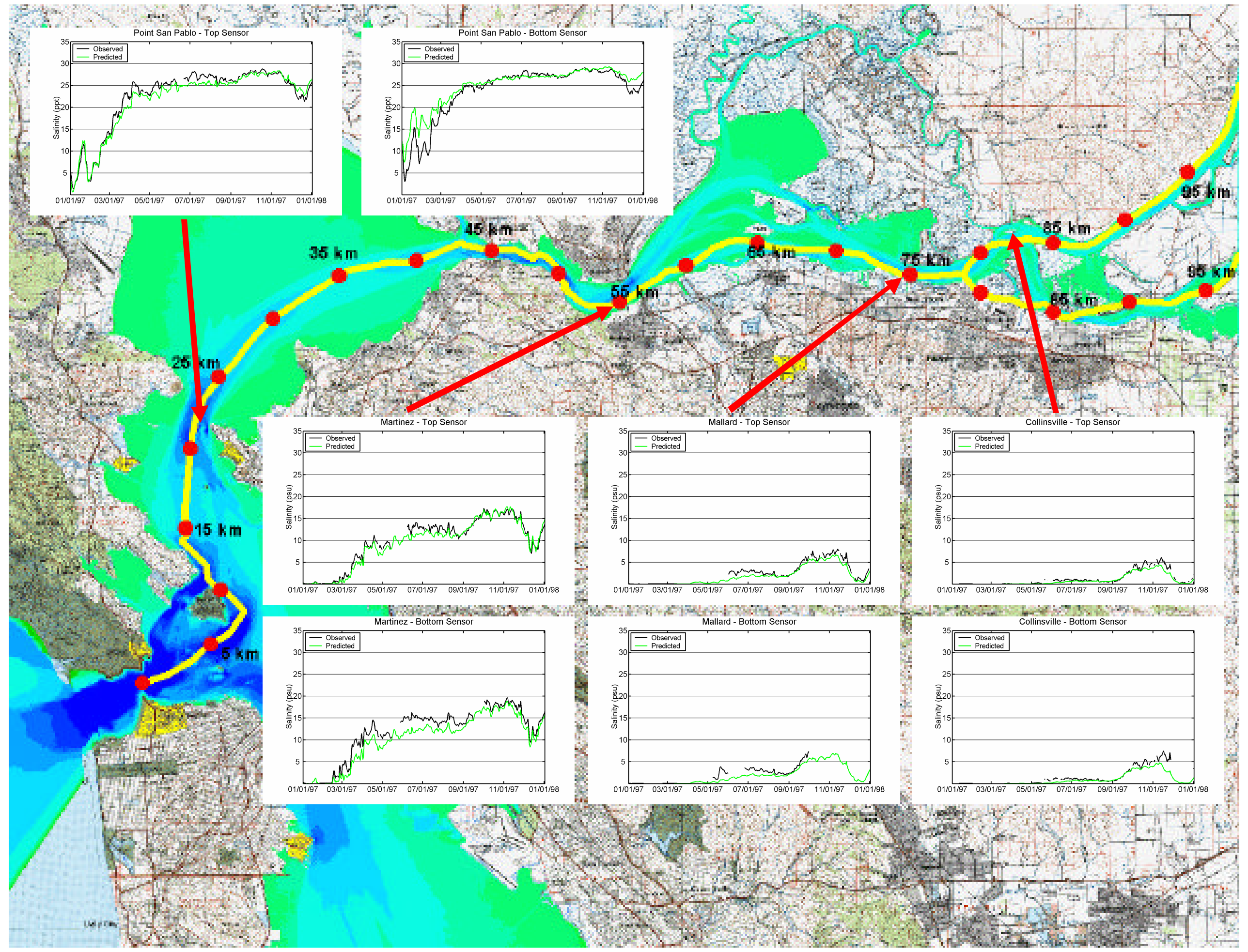
Introduction

Abundance or survival of several estuarine biological populations in the San Francisco Estuary is positively related to freshwater flow (Jassby et al., 1995). These relationships have been described in terms of X_2, the location of the 2 psu bottom salinity. The purpose of this modeling effort is to investigate the potential mechanisms underlying the relationships of fish abundance to flow (" fish-X_2"), which form the basis for the current salinity standard for the estuary. This poster focuses on the prediction of X_2 using the model and comparison of the predicted X_2 with values computed from regression equations and estimated from USGS channel salinity observations.

Model Attributes and Calibration

A 200 meter resolution bathymetric grid was developed covering the estuary from the western Delta to the Golden Gate and extending into the coastal ocean. The vertical resolution of the model is 1 meter, resulting in a total of 621,000 active grid cells. The model is forced by observed tides on the coastal ocean and reported daily outflow values for Delta outflow (CDWR, 1986).

Salinity in San Francisco Bay was predicted during two year long simulations. The first simulation extended from Spring of 1994, a relatively dry year, to Spring of 1995, a relatively wet year. The second simulation extended from Winter of 1997 through Winter of 1998, a period which included some of the highest recorded Delta outflows. During both periods the TRIM model predicts salinity quite accurately, based upon comparisons to USGS RMP channel salinity data (e.g. Edmunds et al., 1995), continuous monitoring data collected by the USGS and other agencies (e.g., Buchanan et al., 1996) and data collected as part of the entrapment zone studies (Burau et al., 1998). In the Figures below the predicted salinity is compared with observed near bottom salinity at all available continuous monitoring stations for the 1997 simulation period. Complete details of the model calibration and comparison with tidal elevation, tidal current and salinity data are documented by Gross et al. (in progress).



X_2 Calculation Review

A method to estimate X_2 from continuous monitoring of surface salinity is outlined by Jassby et al. (1995). This method used salinity observations from six fixed stations maintained by the US. Bureau of Reclamation (USBR, J. Arthur, personal communication) to estimate the location of the 2 psu bottom salinity position. Based on comparison of surface salinity observations against a smaller set of near–bottom salinity observations, the 2 psu bottom salinity location was assumed to correspond to the location of surface salinity of 1.76 psu. Salinity was interpolated between continuous monitoring stations to find the location of the 1.76 psu surface salinity.

In order to fill in periods in which salinity observation data was not available at one or more continuous observation station, the resulting time series of X_2 was fit by a time-series regression model ("Jassby regression") relating current X_2 to the previous day's X_2 and the current value of Q_{out} (Jassby et al., 1995), the net outflow from the Delta, computed by the DAYFLOW program (CDWR, 1986), to yield

$$X_2(t) = 10.2 + 0.945\ X_2(t-1) - 2.30 \log Q_{out}(t)$$

More recently the following alternative regression relation ("Monismith regression") was proposed by Monismith et al. (2002).

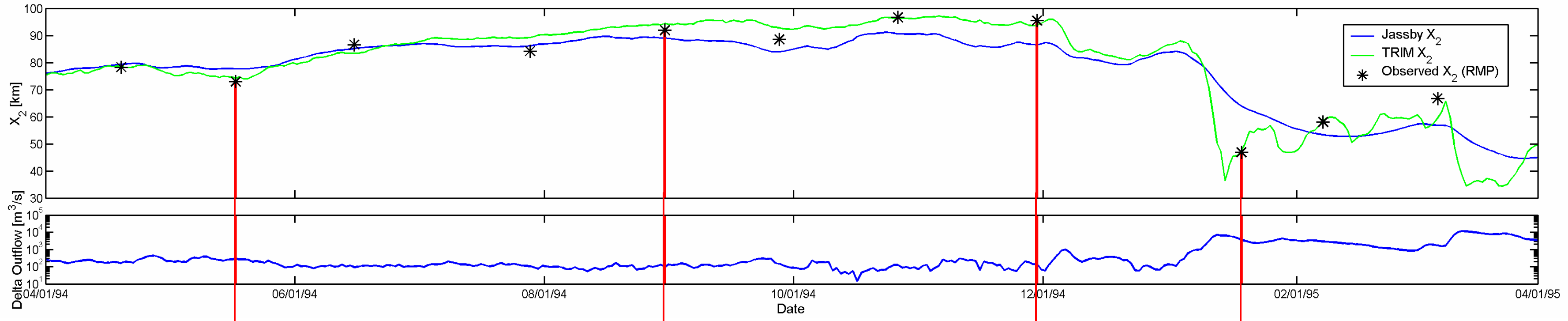
$$X_2(t) = 0.919 * X_2(t-1) + 13.57 Q_{out}^{-0.141}$$

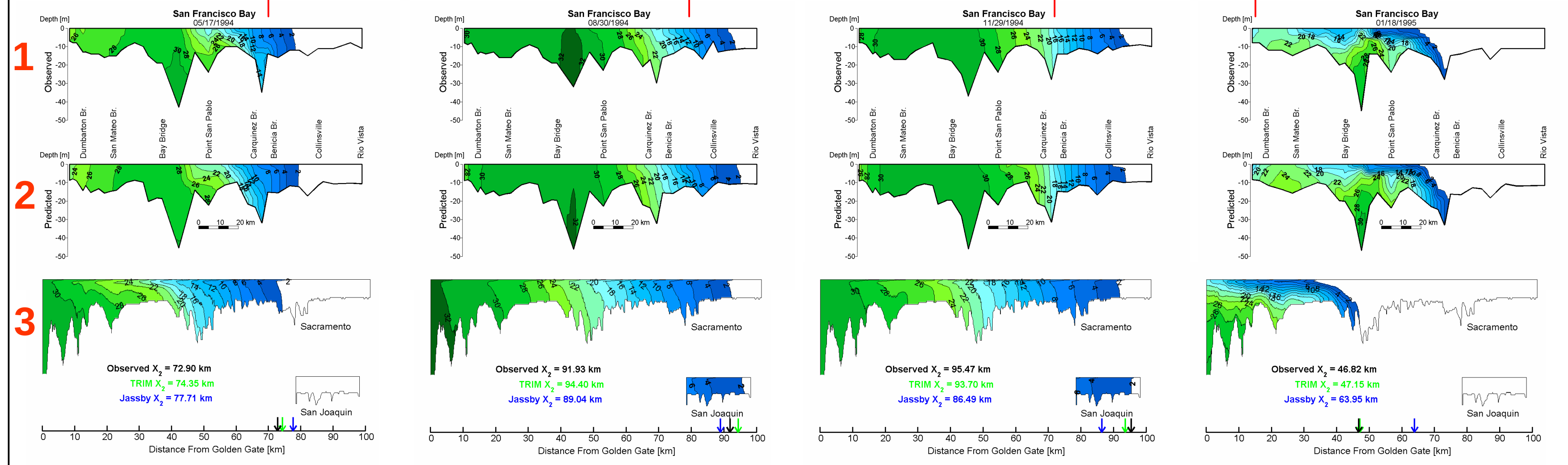
This relation fit the X_2 calculated from continuous monitoring data with an r^2 of 0.98, while the Jassby regression fit the calculated X_2 with an r^2 of 0.986. While both expressions fit the calculated X_2 accurately, the Monismith regression is consistent with theoretical predictions for salinity intrusion (Monismith et al., 2002).

X_2 is no longer calculated from salinity observations, but solely from the Jassby regression relationship.

Calculation of X_2 for 1994 and 1997 Simulation Periods

For the 1994 and 1997 simulation periods, X_2 was computed by three separate methods during two year-long periods each spanning a large range of flow conditions. The top figure shows X_2 calculated from observed Delta outflow using the Jassby regression, X_2 calculated from predicted daily-averaged salinity profiles from the TRIM simulations, and X_2 calculated from the USGS RMP transect observations. The second row of figures compares the observed USGS RMP salinity profiles with the salinity profiles predicted from the TRIM simulations at the corresponding times that data was collected. The third row of figures shows the daily-averaged salinity profile for the day that the RMP data was collected.





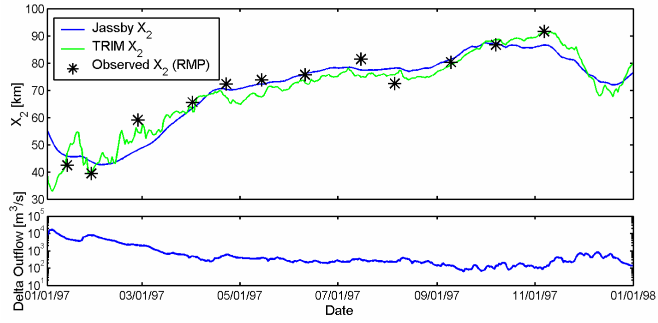
Analysis of X_2 from TRIM Simulations

An advantage of numerical models over field observations is their ability to provide information at high spatial and temporal resolution. Predicted channel salinity at 200 meter intervals along the main channel was daily-averaged and X_2 was calculated by finding the location in the channel with predicted salinity nearest to 2 psu. If this location was in the Delta, X_2 was computed for both the Sacramento River and the San Joaquin River along the transects shown (left panel) and the average distance was used.

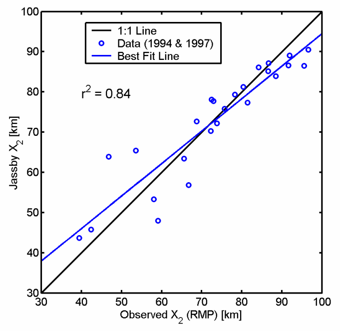
The USGS RMP channel observations are made sequentially along the channel and give a " snapshot" of salinity along the channel. Because X_2 is calculated from daily-averaged salinity, the following approach was used to calculate daily-averaged X_2 from the USGS RMP channel salinity observations:

1) Locate the observed 2 psu bottom salinity contour by interpolating near bottom salinity between adjacent RMP stations. This is considered observed " instantaneous X_2" (1 above).
2) Locate the predicted 2 psu bottom salinity contour by interpolating near bottom predicted salinity between adjacent stations at the same time and place as USGS observations (2 above).
3) Calculate predicted daily-averaged X_2 from model results. This is used as predicted TRIM X_2 distance (3 above).
4) Calculate the difference between the predicted daily-averaged X_2 and the predicted instantaneous X_2. This distance is applied to the instantaneous observed X_2 to obtain daily-average " observed X_2" (shown as * on top figure).

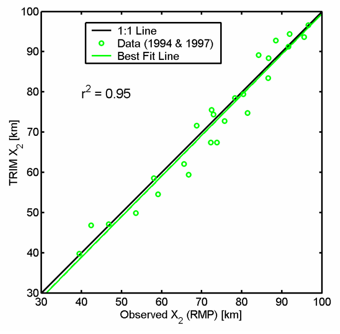
The same approach was used to calculate X_2 for the 1997 simulation period (bottom left). A total of 25 observed RMP channel X_2 values (" observed X_2") were calculated for the two simulation periods. For each of the days that these observations were available, X_2 calculated using the Jassby regression (" Jassby X_2")and X_2 calculated using the predicted daily-averaged salinity profile from TRIM (" TRIM X_2") were plotted against observed X_2. The TRIM X_2 was found to be different than Jassby X_2 during low Delta outflows and high Delta outflows and more similar during moderate flows. The TRIM X_2 matched observed X_2 (bottom right) with an r^2 of 0.95 while Jassby X_2 matched with an r^2 of 0.84 (bottom center). More importantly TRIM X_2 did not exhibit substantial bias relative to observed X_2 while Jassby X_2 was typically 5 to 10 km lower than observed X_2 for high values of X_2.



X_2 predicted from the Jassby regression relation, the TRIM model, and calculated based on USGS RMP channel salinity observations for the 1997 simulation period. The lower panel shows Delta outflow on a log scale.



Comparison of " observed X_2" and X_2 calculated by the Jassby regression relationship.



Comparison of " observed X_2" and X_2 predicted by the TRIM model.

Discussion

The analysis provided here is limited, particularly because only two years of model results were considered. However, it suggests that the ability of existing regression relationships to predict X_2 is limited for high flow or low flow conditions. These regression relationships were developed using a 24 year long record of X_2, and the regression relationships accurately fit that X_2 data record. However, our analysis suggests that X_2 estimates and regression equations could be improved substantially. Several potential shortcomings of the regression relationships, related primarily to the method used to calculate X_2, are outlined below and one is explored in some detail.

1) The approximation that the location of surface salinity of 1.76 psu corresponds to the location of bottom salinity of 2 psu is a rough approximation, particularly for high flows. Analysis of USGS RMP channel salinity observations on 107 different cruises between 1990-1999. During high flow periods when strong stratification is present the bottom salinity may be over 20 psu where surface salinity is 1.76 psu, potentially causing errors in X_2 calculation of over 10 km. During low flow periods, observed bottom salinity varied between 2 and 5 psu at the location where surface salinity is 1.76 psu potentially causing small errors in X_2. Though the pilot RMP observations are instantaneous (not daily-averaged) similar conclusions are reached from analysis of daily-averaged predicted salinity.

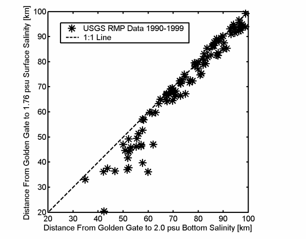
2) The reported Delta outflow values are uncertain at low flows.

3) The large spacing between continuous monitoring stations limits the accuracy of interpolated salinity.

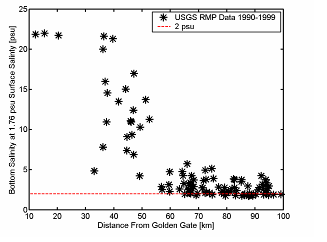
4)The continuous monitoring stations are generally not located at the center of the main channel, while X_2 is intended to represent the location of the 2 psu bottom salinity in the main channel. Therefore lateral variability in salinity, particularly during high flow periods, may limit the accuracy of the calculated X_2.

5)The continuous observation dataset used to compute X_2 extends from 1967 to 1991. Significant changes to the geometry, bathymetry and management of the estuary have occurred during and since this period. Therefore the regression relationships may be less valid for current conditions than they were for historical conditions.

6) X_2 regression relationships have a single response time constant, independent of flow (12 days for the Monismith regression). A longer time constant is probably appropriate at low Delta outflow (Monismith et al., 2002).



Location of 2 psu bottom salinity versus the location of 1.76 psu surface salinity in RMP observations .



Bottom salinity at location of 1.76 psu surface salinity in RMP observations. The red line indicates the assumed bottom salinity (2 psu) corresponding to surface salinity of 1.76 psu in the original X_2 calculations.

A variety of methods are available to calculate X_2 including continuous salinity observations, hydrodynamic modeling, and regression relationships. As outlined in the table to the right, each method shown has distinct benefits and limitations. An ideal method should be predictive so that it can be used as a forward-looking management tool, and provide high spatial and temporal resolution over a long period of time. While observation data measure salinity accurately, they do not provide predictive capabilities. Hydrodynamic models and regression relationships are options for predicting X_2.

Method	Spatial Resolution	Frequency of Observation or Prediction	Duration of Dataset	Predictive
Continuous Salinity Observations	Low, ~ 10 km	Observed every 15 minutes to 1 hour	Decades	No
USGS RMP Salinity Observations	Moderate, ~3 km	Observed typically at 1 month interval	Decades	No
Hydrodynamic Model	High, 200 meters	Predicted once every 1 to 2 minutes	Years	Yes
Regression Relationships	High, continuous	Predicted daily	Decades	Yes

Capabilities and limitations of several approaches to predict X_2. Categories shaded in green show high suitability, yellow shows moderate suitability, and red signifies poor suitability for use as a management tool for predicting X_2.

Conclusions

The TRIM model accurately predicts channel salinity in San Francisco Bay over the entire range of Delta outflows from no net outflow to record outflows. In particular the predicted instantaneous location of 2 psu bottom salinity is consistent with USGS RMP channel salinity observations.

Limitations of the current regression relations between Delta outflow and X_2 appear to be substantial for low flow and high flow. At high Delta outflow the effect of stratification was not accurately accounted for in previous estimates of X_2. Prediction of X_2 for low Delta outflow is uncertain largely due to the uncertainty in Delta outflow at low flows, as noted by both Jassby et al. (1995) and Monismith et al. (2002). In order to predict X_2 for low flow conditions and the response of X_2 to increased outflow (for management purposes), hydrodynamic models are appropriate. In addition to performing well for both low and high Delta outflow, TRIM and other hydrodynamic models are also able to predict temporal variability, including tidal variability of salinity and the effects of the spring-neap cycle on salinity.

The results presented in this poster indicate there is substantial potential to improve upon the current regression relationships and thereby improve the accuracy of X_2 predictions. For low Delta outflow conditions, it may be appropriate to develop a distinct regression relationship using observations for low flow only. Any revised regression equations should be consistent with the RMP data and model predictions presented in this poster and are likely to have longer response time to changes in flow at low Delta outflow than the existing regression relationships.

Literature Cited

Buchanan, P.A., Schoellhamer, D.H., and Sheipline, R.C., 1996. Summary of suspended-solids concentration data, Central and South San Francisco Bays, California, water year 1994: U.S. Geological Survey Open-File Report 95-776, 48 p.

Burau, J.R., Gartner, J.W., and Stacey, M., 1998. Results for the hydrodynamic element of the 1994 Entrapment Zone Study in Suisun Bay. In Report of the 1994 Entrapment Zone Study, edited by Wim Kimmerer, 13-53. Interagency Ecological Program for the San Francisco Bay/Delta Estuary.

Casulli, V., and Cattani, E. 1994. Stability, accuracy and efficiency of a semi-implicit method for three-dimensional shallow water flow. Computers Math. Applic. 27(4), 99-112.

[CDWR] CALIFORNIA DEPARTMENT OF WATER RESOURCES. 1986. DAYFLOW program documentation and data summary user' s guide. California Department of Water Resources, Sacramento.

Edmunds, J.L., Cole, B.E., Cloern, J.E., Caffrey, J.M., and Jassby, A.D., 1995. Studies of the San Francisco Bay, California, Estuarine Ecosystem. Pilot Regional Monitoring Program Results, 1994: U.S. Geological Survey Open-File Report 95-378, 436 p.

Fischer, H.B., List, E.J., Koh, R.C.Y., Imberger, J., and Brooks, N.H. (1979). *Mixing in Inland and Coastal Waters*. New York: Academic Press

Gross, E.S., Koseff, J.R., and Monismith, S.G., 1999b. Three-dimensional salinity simulations of South San Francisco Bay. Journal of Hydraulic Engineering, 125 (11): 1199-1209.

Jassby, A. D., W. J. Kimmerer, S. G. Monismith, C. Armor, J. E. Cloern, T. M. Powell, J. R. Schubel, and T. J. Vendlinski. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological Applications 5:272-289.

Monismith, S.G., Kimmerer, W., Burau, J.R., and Stacey, M.T., 2002. Structure and Flow-Induced Variability of the Subtidal Salinity Field in Northern San Francisco Bay, Journal of Physical Oceanography

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