Modeling and Predicting Intertidal Variations of the Salinity Field in the Bay/Delta

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San Francisco Bay and the Sacramento/San Joaquin Delta have challenged estuarine modelers for some years. Accurate, broad-scale models of this estuary have been in demand by those concerned with its ecological health and the development of sound management policies. A description and better understanding of the dynamics that govern the bay/delta are complicated by the system's complexity, requiring models that are sophisticated enough to capture the subtle physical processes involved.

One approach to simulating daily to monthly variability in the bay is the development of an intertidal model using tidally-averaged equations and a time step on the order of a day. An intertidal numerical model of the bay's physics, capable of portraying seasonal and interannual variability, would have several uses. Observations are limited in time and space, so simulation could help fill the gaps. Also, the ability to simulate multi-year episodes (*eg*, an extended drought) could provide insight into the response of the ecosystem to such events. Finally, such a model could be used in a forecast mode wherein predicted delta flow is used as model input, and predicted salinity distribution is output with estimates days and months in advance. This note briefly introduces such a tidally-averaged model (Uncles and Peterson, in press) and a corresponding predictive scheme for baywide salinity forecasting.

The Uncles/Peterson Model

This numerical model, developed by Uncles and Peterson, simulates tidally-averaged currents and salinities with a time step of one day. Bathymetry data are used to configure the model to the estuary. Daily forcing inputs are precipitation, evaporation, salinity at the mouth of the estuary, freshwater inflow rates, and tidal state that varies with the spring/neap cycle.

The intertidal equations employed by the model are derived by averaging the full equations of fluid motion over a tidal cycle, presumably resulting in equations that represent tidally-averaged motion. However, intertidal estuarine models typically suffer from difficulties in accounting for physical processes lost through this averaging process. The UP model addresses this limitation by building in results from a more detailed, high-resolution intratidal model (Cheng, Casulli, and Gartner 1993). This intratidal model was run through a series of tidal states, varying from a weak neap tide to a strong spring tide. A few important variables relating to the tides, including maximum tidal current speed, tidal energy dissipation, and stress on the bay's bed, were taken from these runs and tabulated according to five ranges of the tidal state. The UP model then accesses these tables with only the indication of each day's tidal state as its input. Thus, some of the crucial information usually lost in the tidal averaging process is recovered, and a great deal of computation is avoided.

The second means by which the UP model reduces its computational load is through its relatively coarse resolution. The model bay is composed of 50 two-layer segments (Figure 1). The upper layer is 5m thick and the lower layer extends to the deepest part of each segment's estuarine section (Figure 2). At each time step, the model calculates across-segment flows and volumetric mixing, which it uses along with the forcing inputs to set up the inverse problem for salinity conservation. This low-resolution, "box-model" approach, when combined with the intertidal method discussed above, allows a simulation of long-term dynamics without massive amounts of computing (the FORTRAN version runs on a work station, 1 minute compute time, about 2 years simulation time).

An example of the UP model output is shown in the series of images in Figure 3. These maps show the simulated evolution of the bay's salinity distribution for water years 1994 and 1995, with darker shading corresponding to saltier water. The upper map shows the high-salinity distribution that typically occurs in October. In the relatively dry water year of 1994, the freshwater/saltwater interface (FSI) was displaced slightly seaward from the delta in October to Carquinez

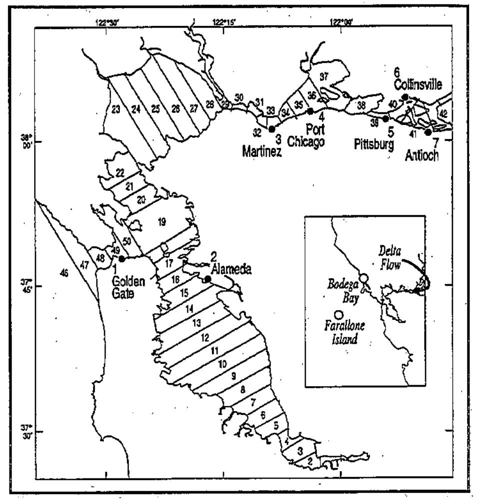

Figure 1
SEGMENTS COMPRISING BAY/DELTA IN THE UNCLES/PETERSON MODEL

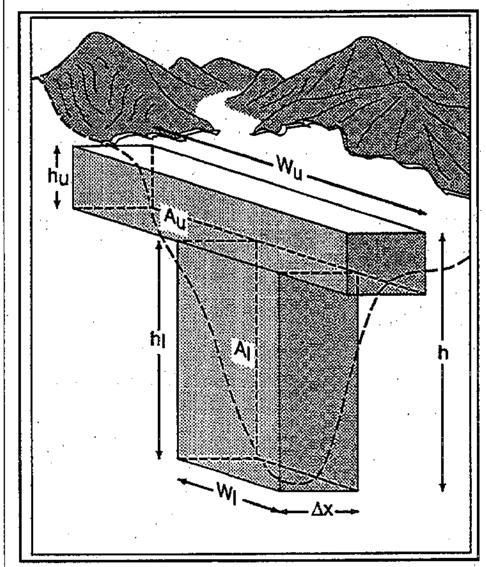

Figure 2
SAMPLE MODEL SEGMENT, UPPER AND LOWER LAYERS
The upper layer is 5 meters thick; the lower layer represents deeper channels.
Layer widths (Wu, Wl) are in the cross-estuary direction.

Strait by April (Figure 3, middle). In subsequent months, delta flow diminished enough to allow tidal mixing effects to take over, and the FSI retreated, reaching the delta again by the water year's end (Figure 3, top). In the much wetter winter of 1995, in which sustained flows of over 2,000 m^3/s pushed the FSI as far as Point San Pablo, freshening the north bays and having a clear effect in the south bay (Figure 3, bottom). By the end of May, Sierra snowpack reserves began to diminish, and the FSI began its slow push up the estuary.

The UP model has not yet been fully tuned to optimally capture the bay salinity variability, but the initial version of the model agrees well with observations on a monthly and perhaps daily time scale. Figures 4 and 5 compare modeled and observed monthly-averaged surface salinities throughout the bay. These exhibit reasonable agreement at Golden Gate and Alameda, the closest stations to the coastal sea. The model and observations at Martinez show very similar trends but with an offset between them. The model consistently underestimated salinity at this station, indicating that the modeled FSI tended to be too far down-estuary (toward the Golden Gate), or possibly that lateral effects may be important at this station (see Figure 10 of Smith and Cheng 1987). Nearer the delta, three stations are grouped: Pittsburg, Collinsville, and Antioch. Figure 5 shows that the model replicates observations quite realistically at these stations, indicating that it may be a useful tool for predicting salinity intrusion and the location of the FSI and the associated turbidity maximum. A comparison of modeled and observed daily salinity at Pittsburg over 1967-1981 (Figure 6) demonstrates that it also captures the interannual changes in salinity over the broad range of conditions that occurred during this epoch.

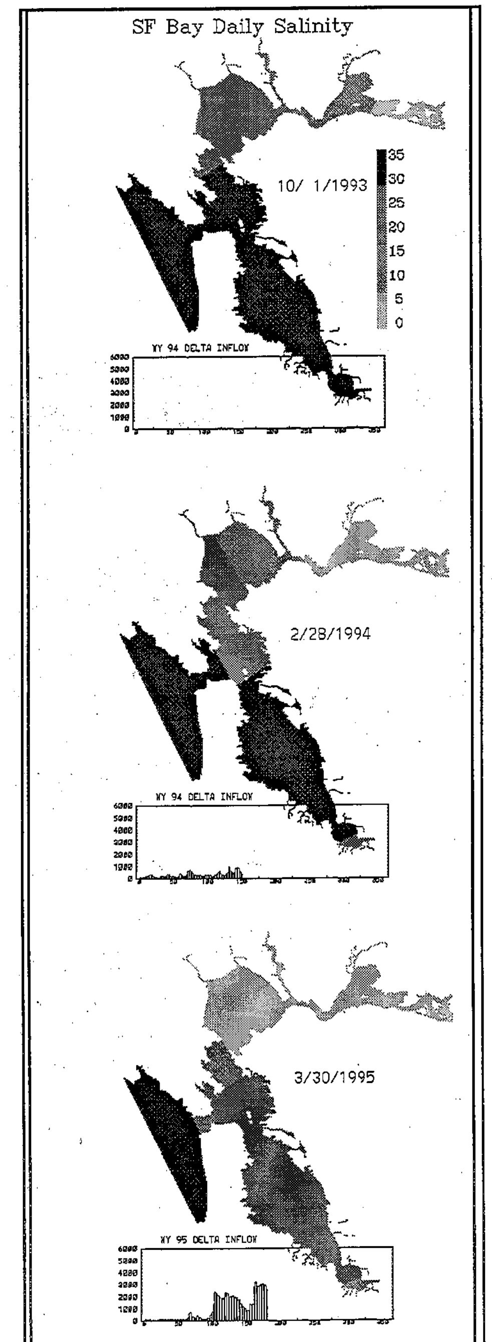

Figure 3
MAPS OF BAY SALINITY
Top: Typical saline October distribution.
Middle: Freshest distribution of dry year 1994.
Bottom: Freshest distribution of wet year 1995.

A Predictive Scheme

The ability of the UP model to simulate the salinity distribution in the bay/delta on daily and seasonal time scales enables it to be used in a predictive scheme. To this end, we have developed a simple statistical flow prediction capability based on a 23-year history of recorded flow data and snowpack indicators in the Sierra. This historical record was partitioned into two subsets: those years with average flow rates above and those below the median, providing two sets of data with which separate predictors for wet and dry years were developed. Late-winter, spring, and summer flows were predicted based on current flow and snowpack values and used to force the model through future months, providing salinity predictions. When such predictions are applied to the 23-year record

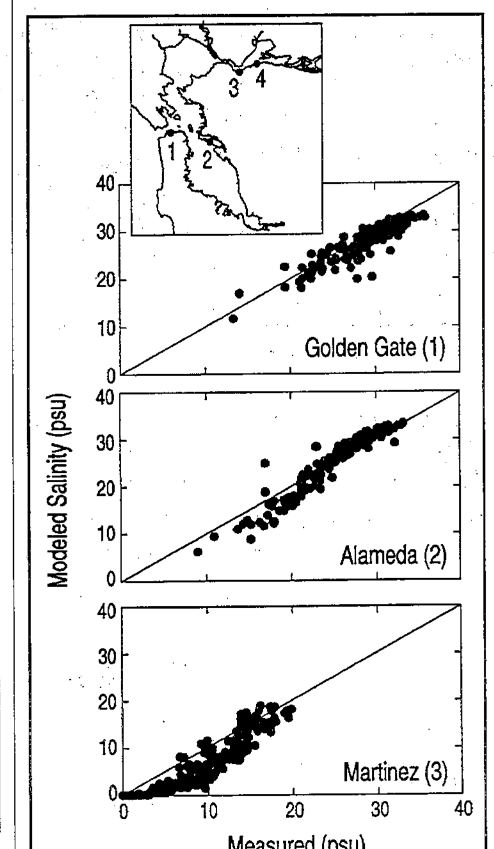

Figure 4
UNCLES/PETERSON MODEL PERFORMANCE AT HIGHER-SALINITY (SEAWARD) STATIONS

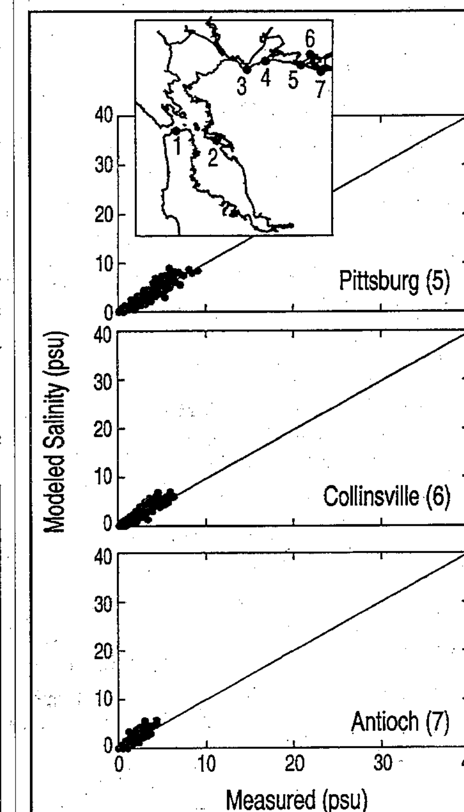

Figure 5
UNCLES/PETERSON MODEL PERFORMANCE AT LOWER-SALINITY (NEAREST DELTA) STATIONS

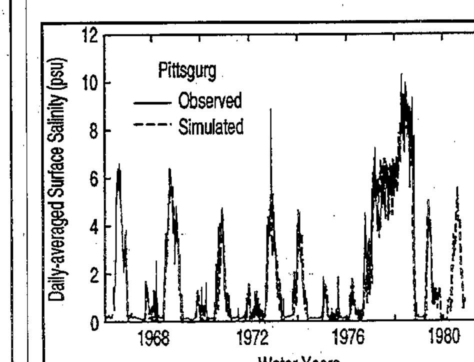

Figure 6
UNCLES/PETERSON MODEL PERFORMANCE (SIMULATED VERSUS OBSERVED) AT PITTSBURG, 1967-1981

for which flow and snowpack records are available, the difference between observed and predicted flows is considered to be due to the effects of weather. In this way, two 23-year ensembles of weather effects are determined, associated with the wet-year and dry-year predictors. Then, when a new prediction is developed, these multiple realizations of weather can be added to it, and the resulting spread of salinity represents the distribution of the weather's potential influence on the bay/delta. To demonstrate, predictions of surface salinity at Martinez, in Carquinez Strait, have been developed for 1994 and 1995 (Figure 7).

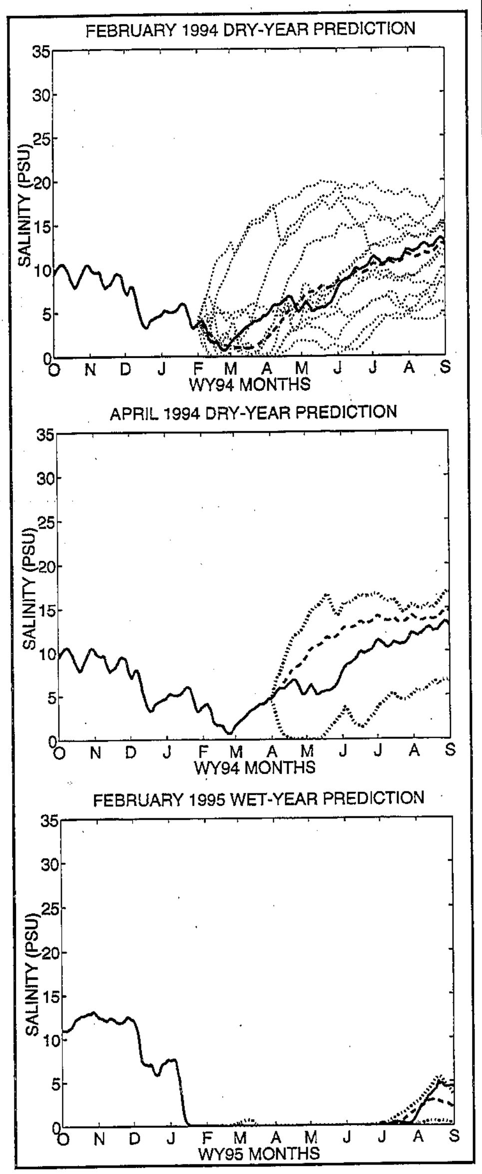

Figure 7
UNCLES/PETERSON MODEL PREDICTIONS OF SALINITY AT MARTINEZ
Top: For 1994 from February 1 conditions.
Middle: For 1994 from April 1 conditions.
Bottom: For 1995 from February 1 conditions
Hindcast salinity from observed flow (solid lines), predicted salinity (heavy-dashed lines), and distribution of weather effects (light-dashed lines).

The upper plot shows the dry-year prediction applied to information available on February 1, 1994. The predicted salinity agrees remarkably well with the hindcast salinity. This results because 1994 was very dry, and by late February, freshwater flows were already small enough that tidal mixing had begun to dominate the dynamics. This highlights the strength of the UP model as an accurate predictive tool in particularly dry years, when salinity forecasts tend to depend strongly on hydrodynamics of the bay. In the next two plots, the effects of the weather ensemble have been replaced with curves representing the 10^{th} and 90^{th} percentile of the prediction for clarity. The middle plot in Figure 7 shows the April 1 dry-year prediction for 1994. One would expect some improvement in the prediction, since most significant events affecting freshwater flow occur in winter and spring, but the April prediction is poorer than February's. Part of the reason for this is that 1994 was so dry, lowering the relative significance of the earlier months over the later ones. The final plot (Figure 7, bottom) shows the wet-year prediction for the current wet year. It is, of course, difficult to gauge the efficacy of the wet-year predictor in this case, because salinity was zero for most of the year and changes in predicted inflow would have little effect. Nonetheless, the dynamical accuracy of the UP model enables a reasonably accurate prediction of timing of the year-end rise in salinity.

Summary and Conclusions

The UP model provides a capability to simulate daily-interannual variability in salinity throughout San Francisco Bay. Although the UP model cannot account for lateral (cross-bay) salinity spatial variability, initial comparison with observed daily salinity records at selected stations between the Golden Gate and the delta shows that interannual salinity variations are very well captured over the 23-year history examined so far. The UP abilities in the south bay are not thoroughly illustrated here, but experiments at USGS in Menlo Park (D. Peterson and L. Schemel, personal communication) indicate usefulness there also.

The economy of the UP model in terms of computational requirements and its physically based baywide character make it a model forecast tool. The preliminary efforts shown here are aimed at developing an extended (few days to several months) forecasting capability. Because it is easy to run several predictions of a given water year case, the approach here is toward carrying out an ensemble of forecasts to establish a mean and the level of uncertainty. In the present case, we have used salinity as our predictand, but because the model contains fundamental physical properties (at least in approximate form), it is conceivable that other variables can also be predicted (*eg*, temperature, sediment load, nutrients, *etc*).

Several improvements are envisioned or underway. Developments planned for the UP model include a calibration of each segment's horizontal and vertical mixing coefficients to optimize model performance. Wind effects on evaporation and surface stress will be included, allowing the model to be coupled to a suitable model of the atmosphere. Knowledge of the temperature field would be useful to those studying the biology of the bay, so a thermal component will be added. Variables representing the chemistry such as nutrient content will also be incorporated. The predictive scheme will be improved by developing a more sophisticated predictor of delta flow, along the lines of the extended streamflow prediction procedure that combines historical data with hydrologic model output (Smith *et al* 1992).

References

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Petition to List Spring Chinook

Spring chinook is one of four races of chinook salmon inhabiting some of California's Sacramento Valley streams. Spring run are found in Butte, Mill and Deer creeks off the Sacramento River mainstem; in the Feather River; in the Sacramento River itself; and in a few other small tributaries. Although no spring chinook are presently found in the San Joaquin system, there was a large run to the upper San Joaquin drainage before construction of Friant Dam in the 1940s.

Adult spring chinook move through the delta during the spring toward their natal streams, where they hold in deep, cool pools before spawning in early fall. Not much is known about the juvenile outmigration. Some appear to move downstream as fry, some as smolts, and some as advanced smolts.

Extensive Feather River spring chinook hatchery production, with subsequent planting and straying to some Central Valley streams, has confused the issue as to what constitutes a "wild" spring run.

On August 30, 1995, Senator Tom Hayden submitted a petition to the California Fish and Game Commission to list the spring run of chinook as endangered under the California Endangered Species Act. On advice from staff, the petition was temporarily withdrawn for reformatting and inclusion of additional information then resubmitted to the Fish and Game Commission on October 16.

The next step is for the Fish and Game Commission to publish a notice of receipt in the California Regulatory Notice Register, which starts a Department of Fish and Game 90-day review period. The commission will then schedule the petition for hearing at its first available meeting after review is completed. It appears that the petition could be considered at its meeting in Redding on March 7 and 8, 1996.

At the meeting, the Fish and Game Commission can:

- Reject the petition.
- Conclude that the petition is warranted and make the spring run a candidate species.

If the Fish and Game Commission finds the petition to be warranted, it will solicit public comments during a 45-day review period and instruct the Department of Fish and Game to prepare a status review of the spring run. The status review will include an analysis of the best scientific information and a conclusion as to whether or not the petition is warranted. The review also includes information on critical habitat and management actions needed to recover the species.

If all goes according to schedule, the Fish and Game Commission will consider final disposition of the petition at its March 1997 meeting. The public will be able to comment at this meeting and will have access to the status report. If the commission finds that the petition is warranted, it will publish a notice of finding and proposed rule-making to list the spring chinook as threatened or endangered.

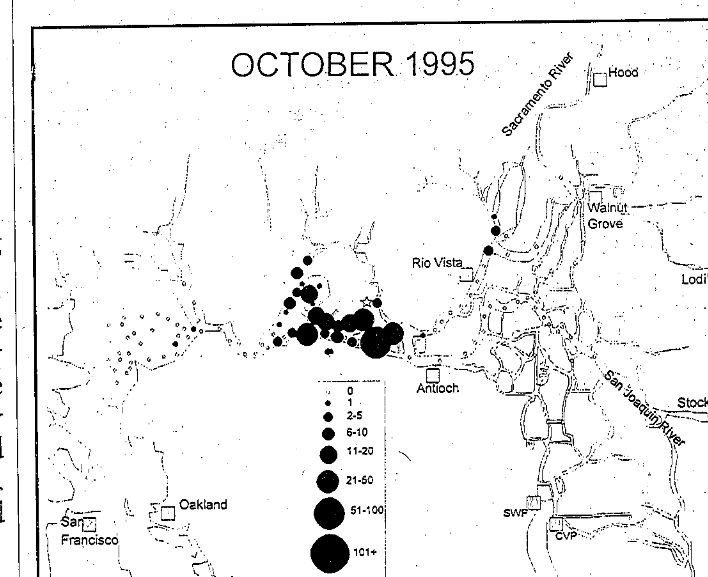
Delta Smelt October Midwater Trawl Survey Results

Leo Winternitz, Department of Water Resources

Results of the October midwater trawl survey indicate a delta smelt distribution centered around the Suisun Bay area, with a few fish found in San Pablo Bay and in the Sacramento River near Cache Slough. Results also indicate a fairly high abundance index for the month. A total of 326 delta smelt were collected, for an index of 349.6. Combined with the September index of 126, the 2-month index is 475.6. With November and December left, the year's abundance index could be around 600. The relatively high September and October index is surprising, given that delta smelt were coming off the lowest adult abundance index on record (1994 adult index of 101.2) into a very wet year. Wet years such as 1995 along with dry years such as 1994 have been considered stressor years for the species. Historically, delta smelt survival is poor in these types of years.

Not all species appeared to do well this year. Based on the summer and fall tow-net and midwater indices, striped bass survival appeared to have been low. Apparently, environmental factors that provided for relatively high delta smelt survival did not do the same for striped bass. What are these factors? Why is delta smelt survival up given they came off the lowest adult abundance index on record into a stressor year? Results from the midwater trawl survey continue to puzzle biologists working on the species. We continuously learn there is much we do not know about delta smelt.

Anybody with ideas, please contact the Resident Fish Project work team at 916/227-7548 or lwintern@water.ca.gov.



DELTA SMELT COLLECTED DURING OCTOBER IN THE FALL MIDWATER TRAWL
Delta Smelt Collected = 326
October Abundance Index = 349.6

The Department of Fish and Game, the lead agency for the midwater trawl, develops the delta smelt indices.
Personnel from other agencies assist in the data collection.