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

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Chapter 10:
Planning Tide at the Martinez Boundary

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10 Planning Tide at the Martinez Boundary

10.1 Introduction

The variety of study most frequently conducted by the Delta Modeling Section is the *planning study.* A planning study is a simulation in which a hydrologic input from a water project simulation model (CALSIM) is applied to the Delta to determine specific impacts on water levels, flows and quality. Because planning studies are needed to simulate the impact of a new policy or new facility under a variety of hydrologic conditions, these studies tend to cover large time periods. Currently, DSM2 planning studies simulate 16 years of monthly operations.

The computational burden of such a long simulation has forced modelers to make simplifications. The most important of these is the *repeating tide.* Instead of employing a 16-year-long stage boundary condition at Martinez that includes the spring and neap tides, planning models have employed a single 25-hour-long design tide[1], repeated many times over. After approximately a half dozen 25-hour cycles, the tide reaches a dynamic equilibrium with the inflow and pumping boundary conditions, which are held constant over a month. Once the equilibrium is achieved, the cyclical (25-hour) equilibrium flow regime is repeated over the entire month without the need for further hydrodynamic calculations.

Computational power has improved, and the Delta Modeling Section has begun to experiment with more realistic tidal boundary conditions. This chapter describes the construction of a new 1968-to-1999 planning tide (Martinez stage at a 15-mintue time step) for this purpose. The goals for the new tide are realism, simplicity, and consistency. Higher accuracy filling of historical records is discussed elsewhere (Ateljevich 2000). The method presented here comprises two components: (1) an astronomical model to generate accurate harmonic components and spring-neap variation, and (2) a filtration of the San Francisco NOAA tidal station data to estimate long period fluctuations due to barometric changes and nonlinear tidal interactions. The model relating San Francisco to Martinez is based on residuals from a preliminary harmonic analysis, rather than the entire tide.

The tidal stage boundary and tidal salinity boundary must be estimated by methods that are consistent. Tidal salinity estimation is discussed in Chapter 9.

10.2 Available Data

The IEP database, http://wwwiep.water.ca.gov/dss/, has water level observations that list a number of stage stations in the estuary going back to about 1986 to 1988 (including Martinez). Before this time, consistent data are available only at the NOAA station in San Francisco. For the sake of consistency, it was decided to use only San Francisco data to help generate the 1968-1999 planning tide, rather than to weave data in and out from stations with limited availability.

[1] Some say “19-year mean tide”.

10.3 Tidal Composition

Ateljevich (2000) gives a qualitative description of tidal observations between San Francisco and Suisun Bay. Over this stretch of the estuary, tides are predominantly astronomical. This is particularly true at San Francisco – Munk and Cartwright (1966) cited San Francisco as an example of a particularly well-behaved harmonic tidal station. Martinez, being farther upstream, is slightly distorted compared to San Francisco. The tide is less sinusoidal, contains evidence of friction, and is occasionally influenced by very high values of Delta outflow. Since these shallow water phenomena are generated mostly between San Francisco and Martinez, the San Francisco tide is not much help in estimating them.

Fortunately, however, the most important deviations from a harmonic prediction are not distortion, but rather long period (4 day – 1 month) fluctuations due to barometric events and long wave non-linear interactions between tidal constituents. Figure 10-1 shows the tide at San Francisco and Martinez after the application of a low-pass tidal filter to remove diurnal, semi-diurnal and higher frequencies. The magnitude of low frequency fluctuations is up to several feet. Note that the tides at San Francisco and Martinez are also very similar in character at these frequencies. It is this similarity that we hope to harness.

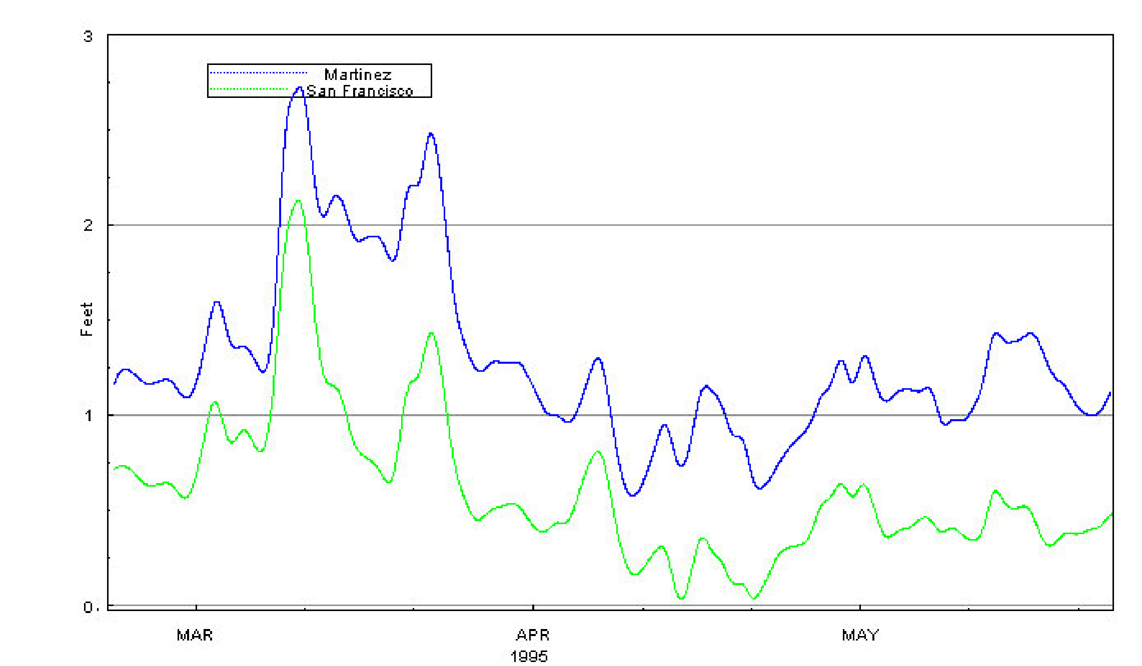

Figure 10-1: Stage After Application of a Low Pass Tidal Filter.

10.4 Astronomical Estimation

As in Ateljevich (2000), the model relating Martinez to San Francisco concentrates on the tidal residue – the portion of the tide that remains after removal of the main harmonic components. The formation of these residuals requires a harmonic estimate at both stations. The harmonic model is taken to be of the form:

$$z_{astro}(t) = \sum_{i=1}^{N} f_i a_i \cos(\omega_i t + \phi_i + u_i) \qquad \text{[Eqn. 10-1]}$$

where $z(t)$ is the water surface height, at time t, ω_i are known frequencies associated with astronomical motion, a_i and ϕ_i are amplitude and local phase, and f_i and u_i are slowly varying amplitude and phase adjustments, as tabulated by the National Ocean Service (see Schureman 1941). The nodal adjustments are taken to be constant over each calendar year. Nodal adjustments are required for intermediate-sized (2- to 19-year) tidal records in order to compensate for the effects of satellite frequencies – clusters of frequencies so close to the "main" tidal frequencies that they cannot be resolved without an extremely long record. Tidal constituents (N) are selected as follows:

- Candidates are chosen from the standard NOS tabulation of common constituents. These are submitted for inclusion according to their magnitude in the tidal (gravity) potential, on the assumption that magnitude in the ocean tide is roughly proportional to magnitude in the tidal potential.
- Constituents with amplitudes less than a threshold (say, 0.01 feet) are dropped.

In the context of the residual model described in the next section, it turns out to be beneficial for the astronomical models for San Francisco and Martinez to be derived from the same time period. Since this limits us to the period for which Martinez observations are available, we will not be doing the best we possibly could at San Francisco. Specifically, by confining ourselves to a 10- to 15-year record, we forgo the opportunity to estimate constituents that resolve over a 19-year nodal cycle. Recall, however, that San Francisco plays only an auxiliary role in this process. Our goal is to generate similar residuals at San Francisco as at Martinez, rather than to eliminate error at San Francisco altogether.

10.5 Residual Tide

As mentioned in the previous section, the main model between stations is based on astronomical residuals. After experimentation with several model sizes, it was decided that the following rudimentary linear model is appropriate for relating Martinez residual tide to that at San Francisco:

$$z'_{mtz}(t) = 0.50\left[z'_{sf}(t-1) + z'_{sf}(t-2)\right] \qquad \text{[Eqn. 10-2]}$$

where the primes indicate residuals from the harmonic model and time is in hours. The number 0.5 was obtained through ordinary least squares (OLS). OLS is asymptotically efficient for estimating this model. Regression statistics such as R^2 are not appropriate due to time correlation of the errors, thus R^2 is not reported here.

10.6 Reconstruction

After the residual at Martinez is estimated using Equation 10-2, the tide must be reconstructed:

$$z_{mtz}(t) = z_{astro}(t) + z'_{mtz}(t) \qquad \text{[Eqn. 10-3]}$$

In order to avoid large, wasteful errors simply from interpolation, it is recommended that the astronomical estimate be at a time step no coarser than 15 minutes and that the residual $z'(t)$ be interpolated from one hour to the finer time step *before* being added to the astronomical estimate. As long as these recommendations are followed, the actual interpolation method (linear, spline) is not particularly important. The author used a fourth order shape-preserving spline due to Huynh (1993).

10.7 Implementation and Discussion

The residual model described above was embedded in a VPlotter session (see Sandhu 2000) and used to prepare a 1968-to-1999 tide. The top plot of Figure 10-2 shows the Martinez tide residuals for the planning tide (with the aid of the San Francisco station) and for the astronomical model. The rms error is reduced 50%, from approximately 0.3 to 0.2 feet, and the number of excursions to a magnitude of 0.5 feet or more has been reduced dramatically. The bottom plot is the tidal average (through use of a Godin filter) of these same residuals. From this plot, it is clear that long wave variation is now confined to a very small band of about ±0.15 feet, confirming that critical long-period variation has been properly estimated and the error statistics are now dominated by distortion and non-linear shallow water effects.

Compared to the best historical filling algorithms, the method is accurate, simple and computationally inexpensive. However, there is at least one caveat that applies to the approach. Long-period variation is still not predicted from physical principles. The long-wave component must be regarded as the realization of a seasonal random process.

Why is this important? Because, at least in theory, the barometric events that affect ocean water levels are related to storms affecting the major rivers. This presents no difficulty when the planning study is conducted using historical hydrology. However, under contrived alternate hydrology, any correlation between mountain hydrology and ocean events will not be preserved. This shortcoming becomes relevant only during major storms, because the correlation is small. For instance, the sample correlation between combined rainfall at two precipitation gages in the American River basin and San Francisco ocean heights (or changes in ocean heights) is less than 0.05. Any scheme sophisticated enough to relate storms to pressure and then pressure to ocean levels would not meet the simplicity requirements for this project.

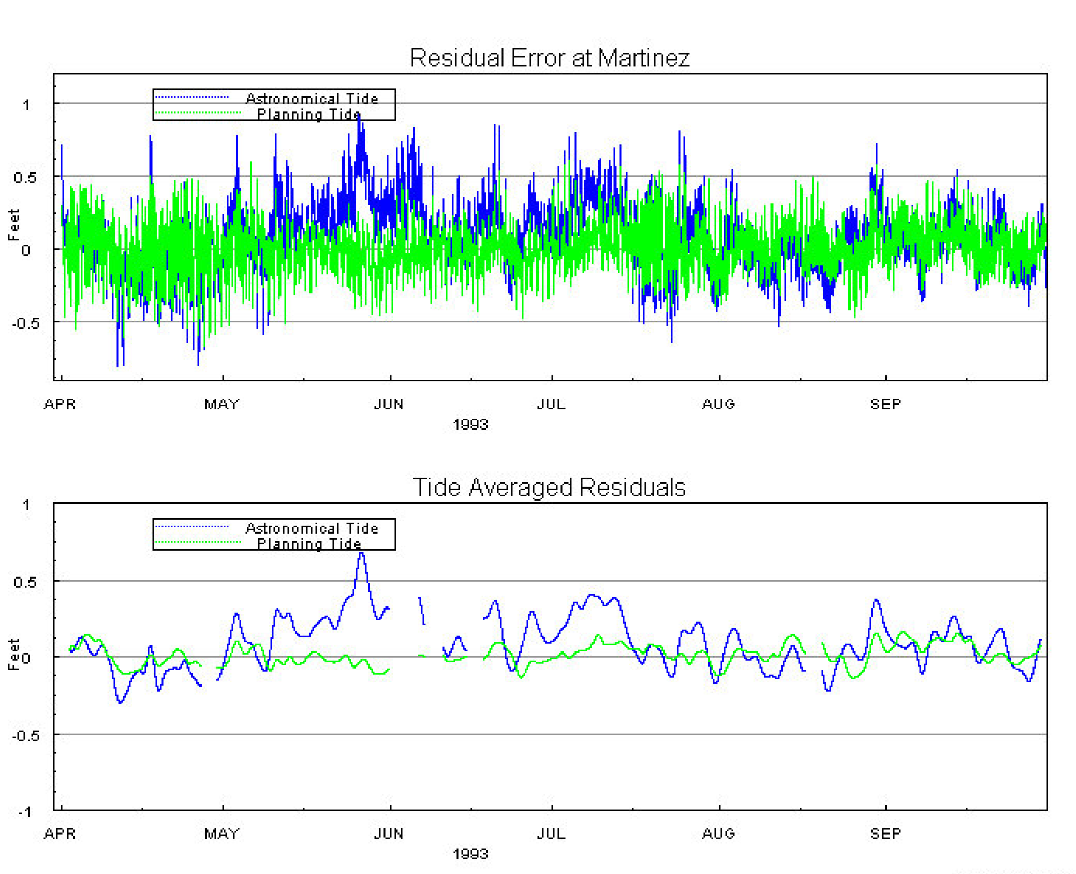

Figure 10-2: Comparison of the Planning and Astronomical Residual Tides in 1993.

10.8 References

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