mean flow in spring, and it usually has a much sharper rise. Because of this abrupt onset of the spring pulse, it would be valuable to understand and predict the character of the pulse in a given year. Both seasonal snow accumulation (late fall through spring), and spring atmospheric circulation play an important role in the timing of the spring pulse. Usually, a larger accumulated snowpack produces a later spring pulse. The spring weather pattern that triggers the pulse features a strong western high pressure ridge; this atmospheric forcing produces widespread warming presumably because of strong solar heating of the snowpack. Importantly, there is an overall coherent pattern of spring pulse over the high elevation watersheds in the West. Inspection of the western United States. stream gage dataset indicates that the Happy Isles record provides an index of the spring pulse over a much broader region of the high elevations, including the Sierra and the Rocky Mountains. Thus, the Merced Happy Isles gage provides a convenient index of a widespread western United States spring runoff pulse, although it may not be the optimum such index. Work to better elucidate this pattern and to identify coherent schemes for predicting the spring pulse is underway by USGS researchers, along with collaborations with Scripps Institution of Oceanography, NOAA Climate Diagnostics Center, and NASA Goddard Space Flight Center.

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Diagnosing the Flood of 1997 in San Francisco Bay with Observations and Model Results

Noah Knowles, Dan Cayan, Reg Uncles, Lynn Ingram, Dave Peterson

The flooding in January 1997 resulted from a series of very warm storms (freezing levels in excess of 9,000 feet) in late December through early January that followed the buildup of a massive snowpack from earlier storms in December. A more restrained sequence of storms in late January produced a second pulse of discharge, but this remarkable early winter was followed by the driest February/March period on record (California Department of Water Resources). The flood of January 1997 provides a unique opportunity to study the effect on San Francisco Bay of a strong freshwater pulse followed immediately by a very dry period. Total inflow during the 6-week period December 30 to February 9 is estimated to be 25x10^9 cubic meters, nearly four times the mean volume of the bay (delta flow shown in Figure 1). Water years 1983 and 1986 are the most recent years to exhibit such a high aggregate flow volume, with a smaller peak but a broader delta flow hydrograph in 1983 and a delta flow in 1986 that was nearly identical, though delayed, to that of water year 1997.

During the course of this year's flood, multiple "snapshots" were taken of along-estuary and vertical distributions of salinity, oxygen isotopes, suspended sediment, chlorophyll and other important indicators of water quality (see USGS data at http://sfbay.wr.usgs.gov/access/wqdata). Here, the evolution of two tracers, salinity and the oxygen isotope ratio ($\delta^{18}O$), during the flood will be diagnosed with the aid of an intertidal water quality model, the Uncles-Peterson model. The model will be used to fill gaps in the observations, allowing a more complete examination of the flood's impact in the bay.

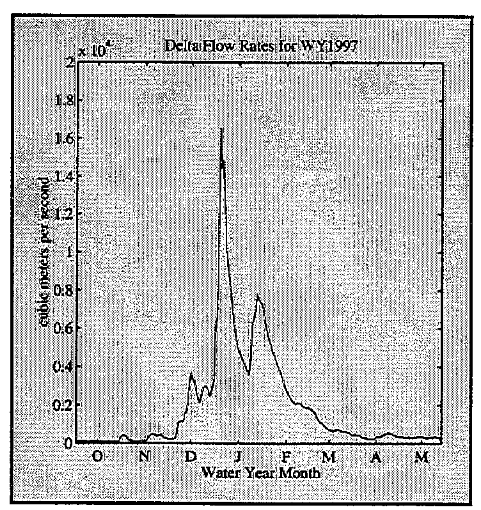

Figure 1
WATER YEAR 1997 DELTA FLOW HYDROGRAPH

Model and Input

The Uncles-Peterson model (Uncles and Peterson 1996; Knowles *et al* 1995) uses coarse resolution (Figure 2) and tidally-averaged physics to generate simulations of the residual laterally-averaged velocity and salinity fields. Computations with the model are relatively fast, so a 40-year run on a current generation workstation takes only about 20 minutes. Also, the capability to simulate other solutes has recently been added and is being explored in light of the variety of data available to characterize the bay. The model is driven by precipitation, evaporation, ocean boundary salinity, an indicator of the spring/neap state of the tide, and freshwater inflows. To simulate the recent flood, delta flow estimates were provided by Sheila Greene (DWR), and local inflows were assumed to be proportional to the delta flow. Ocean salinity was fixed to its climatological mean, and precipitation directly over the bay was neglected. These assumptions were made due to lack of appropriate data, but the resulting errors should be minimal because tidal forcing and delta flow typically dominate the bay's variability.

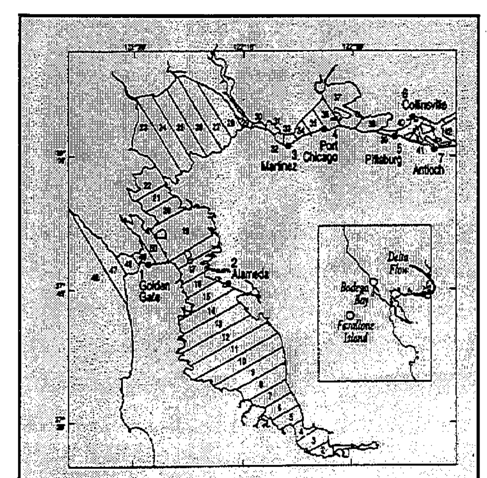

Figure 2
SEGMENTATION OF THE UNCLES-PETERSON MODEL

Salinity and Isotope Data

The data used to characterize salinity variability are from 14 cruises conducted by the USGS between October 16, 1996, and April 10, 1997. Salinity time series data were also provided by Larry Schemel (USGS, Menlo Park) at three stations in the North, Central and South bays. The oxygen isotope data are from four cruises between January 13 and April 1, 1997.These data provide a sparse but broad spatial and temporal coverage that, when used in combination with model results, yields a comprehensive picture of the flood's influence in the bay.

Results

Figure 3 compares model salinity results with the three time series. The model tracks salinity well at these stations, though it appears to overestimate South Bay salinity before the flood peaks and underestimate it afterwards. Comparison with the cruise data shows the same results, with good agreement throughout the bay and slight errors in South Bay. The problems in South Bay are partly due to the lack of local inflow data.

The evolution of the baywide salinity field is shown in Figure 4. Major features of the flood are apparent in the observed salinity data, and the model output fills in the gaps to provide a more complete picture of these events. The inflow pulse that initiated the year's salt field displacement was centered on December 15 and is visible from the delta seaward to about Angel Island. Subsequently, the peak floodwater inflows centered on January 1 and January 27 generate freshwater pulses that are distinguishable as far south as central South Bay. South of that they lose their coherence, but a model run with no local South Bay inflow clearly indicated the diffusion of delta water deep into South Bay. In another run, South Bay inflows were included, but delta water was specifically "tagged" to trace the movement of flood water through the bay. These model results suggest that average delta water content in South Bay rose from a typical dry-season value of around 5% before the flood to 35% after the peaks had subsided. This compares to an average value for the annual maximum delta water content in South Bay of around 20%, generated from a simulation of water years 1967-1993.

Figure 5 shows the evolution of the model bay's total freshwater content for the current water year as well as for a 27-year average. Although the peak freshwater content was nearly 30% higher during the 1997 flood than in the average year, the subsequent dry spell allowed freshwater content to quickly drop below the mean value, resulting in higher-than-average salinity despite the early-winter floods.

The model was run with the mean (constant) tidal state as well as the actual tidal state variations to examine the effect of variations in tidal mixing. The December 15 pulse was slightly stronger with tidal variations because it occurred during a neap tide. The January 3 pulse was initially strong during a neap tide, but the signal eroded quickly as a strong spring took effect. The January 27 signal was nearly as strong as the January 3 signal, even though the flows were significantly weaker. This was due to the setup from the January 3 pulse as well as a neap tide, which lasted for the duration of this event.

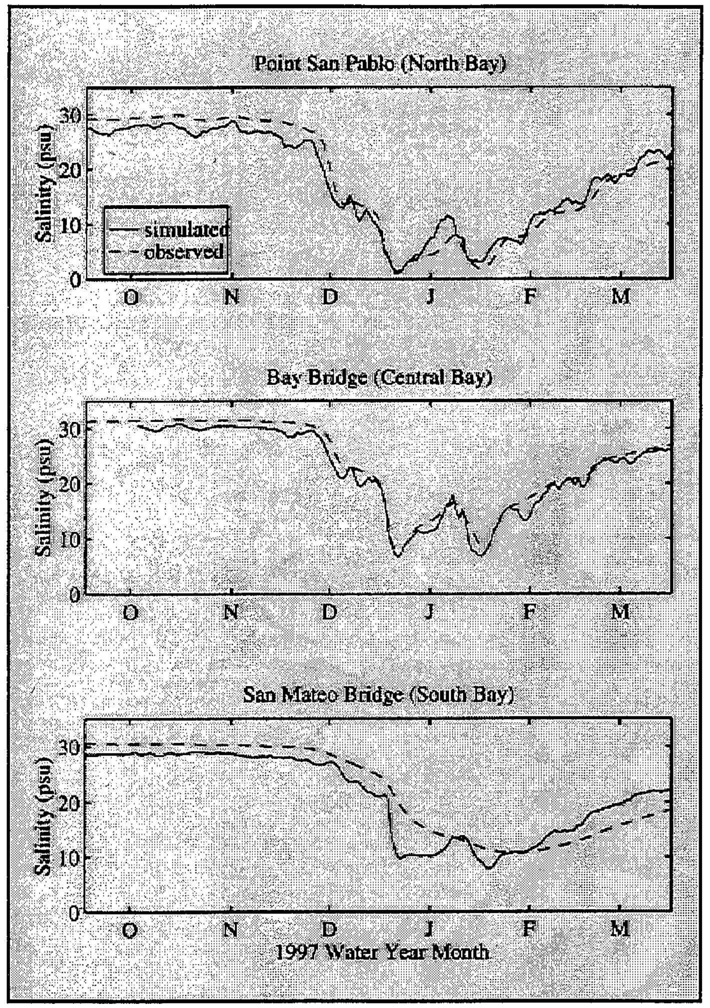

Figure 3
OBSERVED AND SIMULATED SALINITY AT
THREE STATIONS THROUGHOUT THE BAY

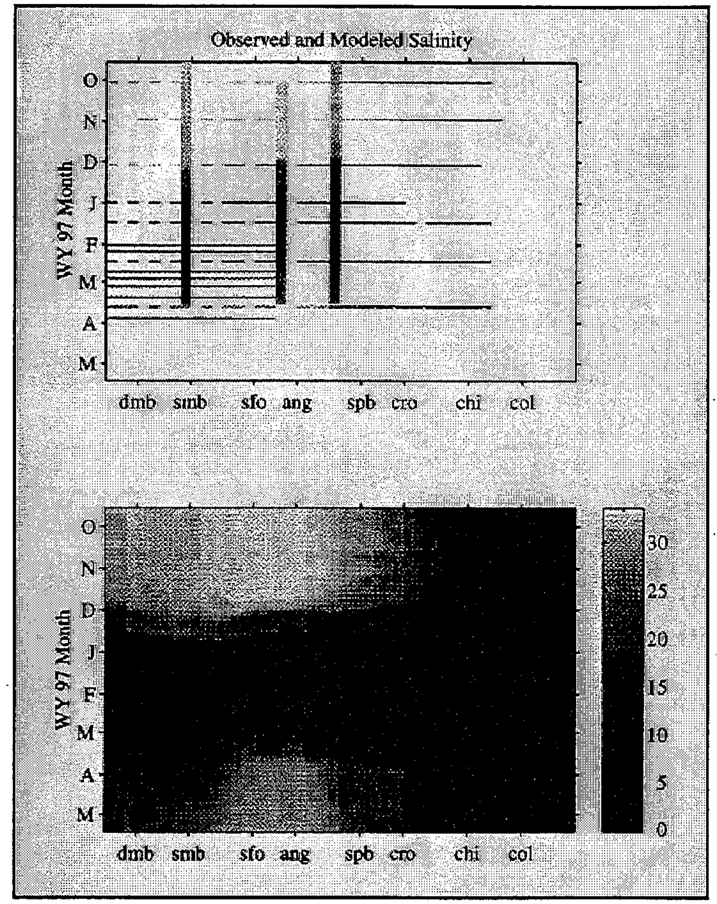

Figure 4
OBSERVED (upper) AND SIMULATED (lower) SALINITY VARIATIONS
Reference points are Dumbarton Bridge, San Mateo Bridge, San Francisco Airport, Angel Island, San Pablo Bay, Crockett, Port Chicago, and Collinsville

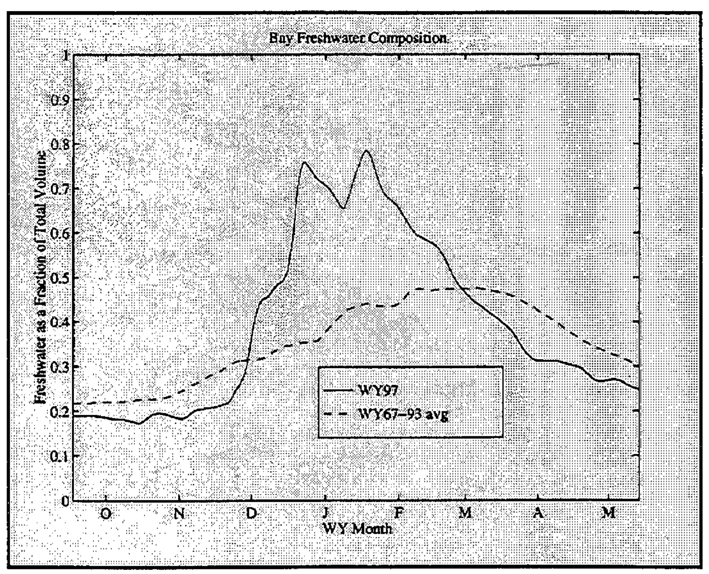

Figure 5
FRACTION OF BAY VOLUME COMPOSED OF FRESH WATER
AS A FUNCTION OF WATER YEAR MONTH

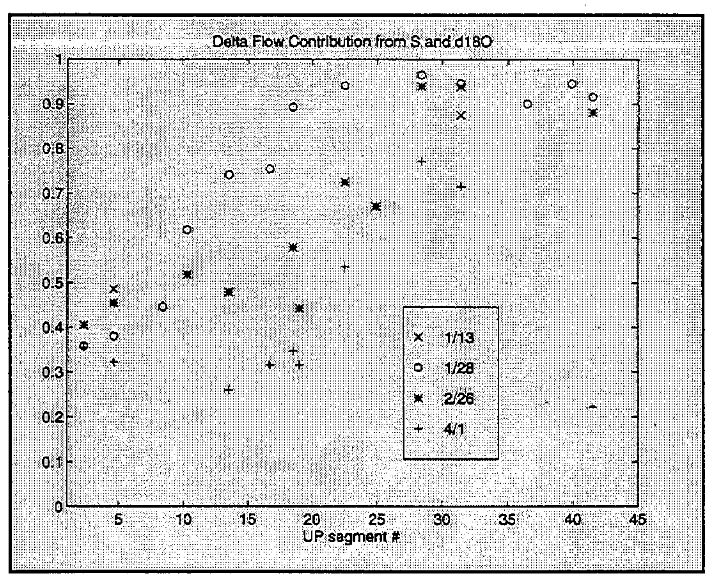

Figure 6
DELTA WATER DISTRIBUTIONS INFERRED FROM
SALINITY AND $\delta^{18}O$ MEASUREMENTS DURING FOUR CRUISES
Refer to Figure 2 for model segment locations.

Total bay modeled salt content reached a minimum of about 40x10^{9} kg on February 1 and had recovered to nearly 150x10^{9} kg by mid-May. This compares to an average minimum over the last 30 years of over 90x10^{9} kg and a typical dry-season maximum of nearly 170x10^{9} kg. The recovery rate between mid-February and mid-April was fairly steady at about 800x10^{6} kg salt per day, or about 5 psu/month at North Bay stations.

The oxygen isotope ratio data ($\delta^{18}O$), when combined with concurrent salinity observations, may be used to infer water composition based on known values of $\delta^{18}O$ for the various water sources (ocean, delta flow, and local inflows). This provides an excellent test of the model's ability to capture the movement of water that underlies the evolution of the salinity field. Figure 6 shows the distribution of delta-sourced waters throughout the bay for the four $\delta^{18}O$ cruises. Although these data are not sufficient to determine the effects of the January 3 flow pulse, the influence of broad pulse centered on January 27 is clear. On January 28, water near the Bay Bridge was 90% delta-sourced, decreasing to about 40% in southern South Bay. This peak distribution agrees well with modeled water composition. As ocean water gradually mixed back into the estuary, delta water composition declines until the entire South Bay is composed of about 30% delta water on April 1.

Conclusions

The combination of model results and observed data provides insight into the impact of extreme events such as the flood of January 1997. Where the accuracy of model inputs or of the model itself is uncertain, observations supply missing information. Conversely, simulations can be used to fill in gaps in the observations. Here, the Uncles-Peterson model fills the gaps in a broad but sparse dataset. The oxygen isotope data help to complete the picture in South Bay, where the model inputs are uncertain. The oxygen isotope data provide an excellent tracer to infer water composition in the bay, and data of this type will continue to aid in future model refinements.

An on-line version of this article can be found at:
http://meteora.ucsd.edu/~knowles/papers/iep97/

Delta Outflow

Kate Le, DWR

Between October 1, 1996, and June 30, 1997, the average Delta Outflow Index was 59,800 cubic feet per second. The largest outflow — 584,500 cubic feet per second on January 3 — was due to increased precipitation and high reservoir flood control releases. Combined SWP/CVP pumping averaged about 6,000 cubic feet per second during this period. SWP pumping was curtailed in December because water demands were being met. SWP pumping ceased in January because Banks Pumping Plant was at full capacity. SWP pumping was curtailed on April 24 due to weed spraying and on May 21 to maintain a high outflow to achieve the number of X_2 days. CVP pumping ceased from January 20, through February 7 for canal maintenance work and from February 11 through February 24 for fish facility maintenance.