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Suspended-sediment dynamics in the tidal reach of a San Francisco Bay tributary

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SUMMARY

To better understand suspended-sediment transport in a tidal slough adjacent to a large wetland restoration project, we deployed continuously-measuring temperature, salinity, depth, turbidity, and velocity sensors since 2010, and added a dissolved-oxygen sensor in 2012, at a near-bottom location in Alviso Slough (Alviso, California USA). Alviso Slough is the downstream reach of the Guadalupe River and flows into the far southern end of San Francisco Bay. River flow is influenced by the Mediterranean climate, with high flows correlated to episodic winter storms (~85 $m^3\ s^{-1}$) and low base flow during the summer (~0.85 $m^3\ s^{-1}$). Storms and associated runoff have the greatest influence on sediment flux. Strong spring tides promote upstream sediment flux and weak neap tides have only a small net flux. During neap tides, stratification likely suppresses sediment transport during weaker flood and ebb tides.

1. INTRODUCTION

Estuarine tributary channels are highly dynamic environments, where conditions can change from fully freshwater to nearly ocean water over a single tide and mean depth and tide range can be similar. Tidal sloughs can serve as the primary connection between watersheds and bays. They typically have low bed slope, and the transport processes that drive constituent fluxes in the sloughs can be very different from riverine and coastal environments. This suggests that materials monitored above the head of tide in the tributary may not make it all the way into the estuary [1].

A large wetland restoration project (www.southbayrestoration.org) is underway in southern San Francisco Bay (SFB) with a goal to convert about 6,000 hectares of former commercial salt evaporation ponds into a mixture of managed ponds and tidal marsh habitat to support a myriad of animals and plants. Two main issues influence the project: 1) much of the land has subsided below mean tide level and will require sediment deposition to reach tidal marsh elevations, and 2) the largest historical mercury mine in the United States is located in the upstream watershed. This means there is relic mercury in the downstream sediments and a continued supply still leaching from the former mine. Therefore, the restoration project managers need to understand sediment transport in the sloughs surrounding the restoration sites to inform them about sediment remobilization and the fate of associated contaminants.

The goal of this study is to identify the major transport direction and dynamics for sediment and quantify the flux in Alviso Slough. This is one component of the multiple-investigator work done in the slough that includes quantifying mercury in the sediments and water column to determine mercury transport, bathymetric surveys to determine regions of scour and sedimentation, and modelling to understand the fate of transported sediment.

2. METHODS

Alviso Slough is a tidal slough located on the southern margin of San Francisco Bay, California, USA that connects the upland Guadalupe River with SFB (Fig. 1). River flow is influenced by the Mediterranean climate, with high flows correlated to episodic winter storms and low base flow during the summer. The Guadalupe River flows year around, although summer base flows are small compared to storm flows (0.85 $m^3 s^{-1}$ and roughly 85 $m^3 s^{-1}$, respectively). The area experiences mixed, semi-diurnal tides with a maximum tidal range of about 3.6 m, and a mean depth at the station of 2.9 m.

The instrument package was deployed beginning in 2010 in the thalweg of Alviso Slough (USGS station #11169750) about 4.4 km from the bay, and the station consists of a near-bottom sonde (0.46 m above bottom) measuring conductivity, temperature, depth, turbidity and dissolved oxygen, and an upward-looking acoustic Doppler current profiler to profile velocity. All instruments collect data on a 15-minute interval and are serviced every four to six weeks for data download, instrument cleaning, and calibration checks following standard USGS procedures [2]. Data gaps in the time series data are the result of biofouling of the sensors, instrument malfunction, or servicing. One limitation in this study is the lack of vertical salinity or density profile data to confirm the presence or absence of water column stratification. A near-surface salinity sensor has recently been installed at the site.

The velocity and stage data collected at the fixed station were calibrated to slough discharge (Q) through boat-collected discharge measurements [3]. Turbidity data from the fixed location was calibrated to cross-sectionally averaged suspended-sediment concentrations (SSC) through boat-collected Equal-Discharge-Increment sampling for suspended sediment [4]. Suspended-sediment flux (Qs) is the product of Q and SSC.

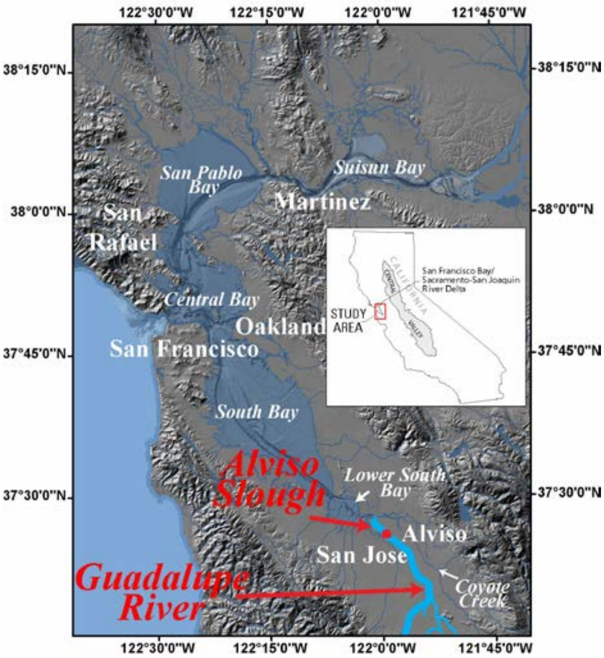

Figure 1. Study area in the southern reach of San Francisco Bay. Red circle denotes the location of the instruments.

3. RESULTS

Discharge in the slough (Fig. 2, top) is tidally modulated, while rainfall-related runoff events in November-December 2012 and March 2014 caused large bayward (positive) Q. The storm event in late December 2012 resulted in bayward discharge for more than 24 hours. SSC (Fig. 2, middle) varied daily with the tide and exhibited a strong spring-neap tidal signal (with higher mean and peak concentrations during the spring tides), while annual peak concentrations typically occurred in April and May of each year. These peak concentrations in the slough were typically decoupled from storm events and are similar to the spring-tide peak concentrations seen during the spring in southern SFB [5]. The cumulative sediment flux results (Fig. 2, bottom) suggest that the primary sediment flux direction was landward, particularly during the summer months, but strongly bayward during the storm events in late 2012 (Fig. 2, bottom, segment 4). Table 1 shows the cumulative sediment flux for each segment; the net over the entire period is -4,040 t. Even with the data gaps, this represents a significant landward movement of sediment in the tidal reach of this slough.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Net Qs (t)	-1,310	170	-1,180	4,730	-3,370	-166	-61	-2,850

Table 1. The cumulative bayward sediment flux in metric tons for the eight segments of the time series (Fig. 2, bottom).

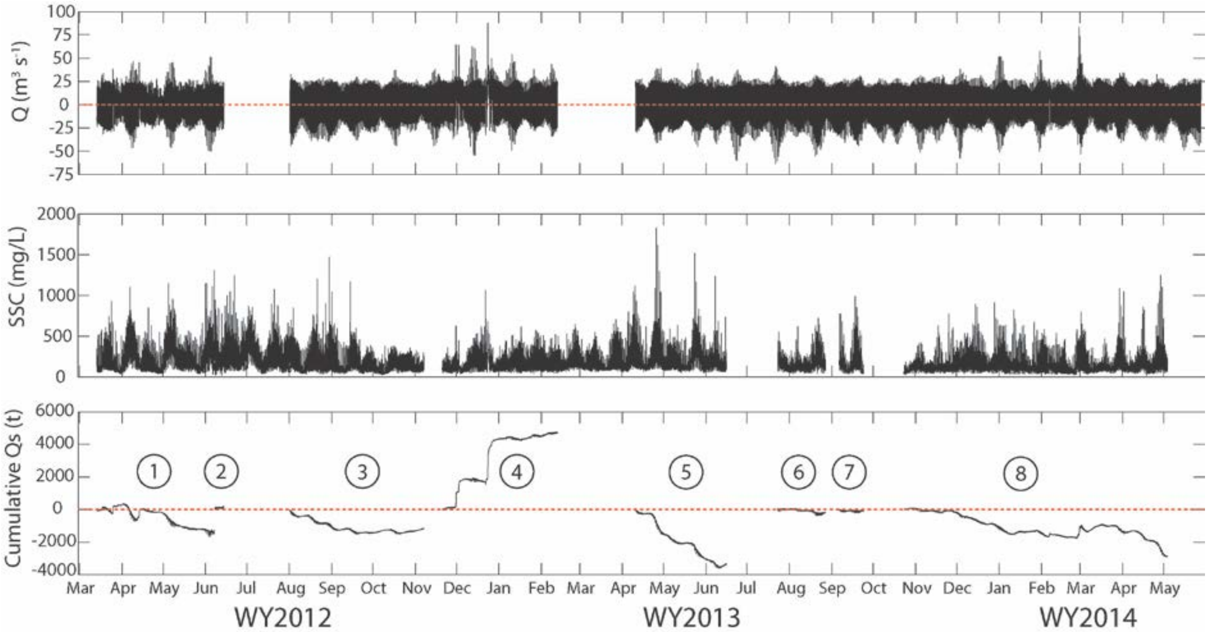

Figure 2. The discharge (top), suspended-sediment concentration (middle), and cumulative sediment flux in metric tons (bottom) in Alviso Slough. Positive values are bayward, negative values are landward. The cumulative sediment flux time-series is reset to zero after each data gap, resulting in eight cumulative flux segments (Table 1).

4. DISCUSSION

Over the time period of our monitoring, sediment flux in Alviso Slough was flood-dominated, except during precipitation-driven runoff events in the Guadalupe River. The spring-neap tidal cycle was the dominant forcing on the SSC and sediment flux, where SSC can more than double with the onset of spring tide.

During spring tides, peak SSC occurs with the advection of the salinity front (Fig. 3) during the latter phase of the stronger daily flood tide. This is coincident with a drop in velocity, suggesting that the front associated with the advection of saltier Bay water up-slough is responsible for the SSC increase, rather than velocity-driven shear. Smaller SSC increases are seen during ebb tides and during the weaker flood tides, but these can be up to an order of magnitude smaller than the advection peaks.

During neap tides (Fig. 4), peak SSC occurs near the peak ebb velocities and tends to stay elevated until low slack tide. SSC peaks again at the beginning of the subsequent flood tide and falls to a base level by the end of the strong flood. This is explained by the remobilization of sediment in the slough during the strong ebb, some sediment settling at low slack tide, and subsequent resuspension of the sediments during the next flood. Peak ebb-tide flux is larger than flood-tide flux (roughly two times larger). It does not appear that there is a strong SSC peak associated with the salinity front during the stronger floods during neap tides. Suspended-sediment concentrations are low during the weaker daily ebb and flood tides. Salinity stays relatively constant from the peak of the strong flood to the peak of the weak flood and again from the peak of the weak flood to the peak of the strong ebb. This constant salinity condition could result from either a well-mixed water parcel trapped by the weak tides that oscillates past the instruments or there could be stratification of the water column. Given that SSC is low and dissolved oxygen shows a steady decrease in these two periods (with peaks associated with slack water and potential water column mixing), it is likely that the water column is stratified, turbulence is damped, and sediment resuspension is minimized. The stratification during ebb tide is likely due to tidal straining [6].

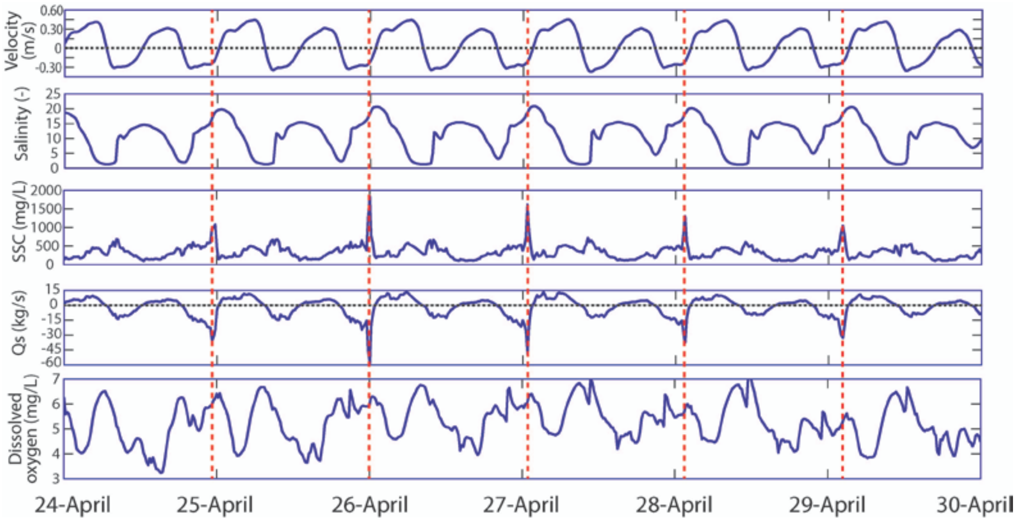

Figure 3. A spring tide period in 2013. Positive velocity and flux are ebb-directed (bayward). Red dotted vertical lines represent periods of peak flood-directed flux. Note the scale differences from Fig. 4.

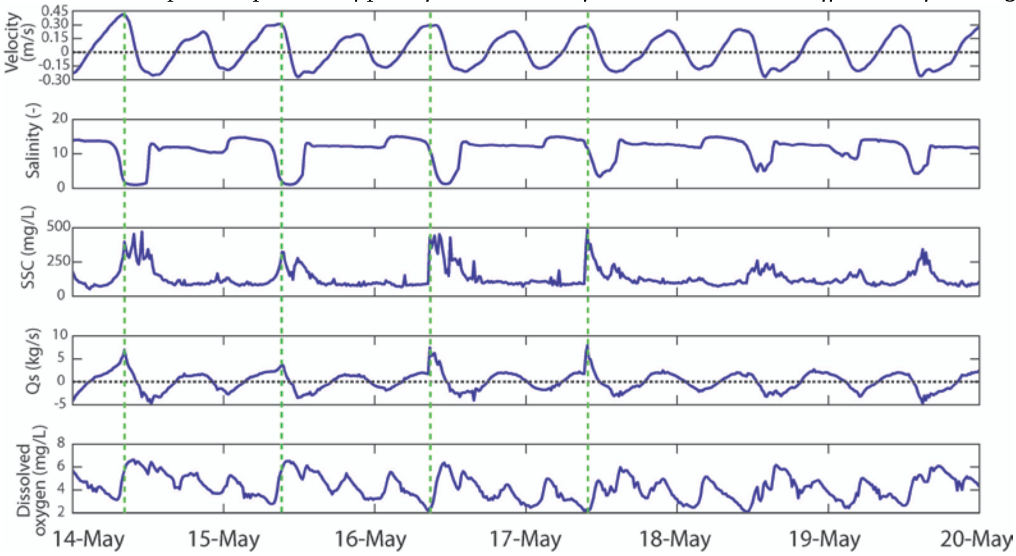

Figure 4. A neap tide period in 2013. Positive velocity and flux are ebb-directed (bayward). Green dotted vertical lines represent periods of peak ebb-directed flux. Note the scale differences from Fig. 3.

Overall, storm events exert the most variability on the sediment flux in a given year and are responsible for most of the advective downstream sediment flux (Fig. 2, bottom). The spring-neap tidal cycle has the most impact on the annual sediment flux, where high SSC associated with advection of the flood tide salinity front during strong spring tides promotes significant landward sediment movement, while weak neap tides have nearly zero net flux. During neap tides, stratification likely suppresses sediment transport during weaker tides.

5. REFERENCES

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