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Calibration of an estuarine sediment transport model to sediment fluxes as an intermediate step for simulation of geomorphic evolution

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Abstract

Modeling geomorphic evolution in estuaries is necessary to model the fate of legacy contaminants in the bed sediment and the effect of climate change, watershed alterations, sea level rise, construction projects, and restoration efforts. Coupled hydrodynamic and sediment transport models used for this purpose typically are calibrated to water level, currents, and/or suspended-sediment concentrations. However, small errors in these tidal-timescale models can accumulate to cause major errors in geomorphic evolution, which may not be obvious. Here we present an intermediate step towards simulating decadal-timescale geomorphic change: calibration to estimated sediment fluxes (mass/time) at two cross-sections within an estuary. Accurate representation of sediment fluxes gives confidence in representation of sediment supply to and from the estuary during those periods. Several years of sediment flux data are available for the landward and seaward boundaries of Suisun Bay, California, the landward-most embayment of San Francisco Bay. Sediment flux observations suggest that episodic freshwater flows export sediment from Suisun Bay, while gravitational circulation during the dry season imports sediment from seaward sources. The Regional Oceanic Modeling System (ROMS), a three-dimensional coupled hydrodynamic/sediment transport model, was adapted for Suisun Bay, for the purposes of hindcasting 19th and 20th century bathymetric change, and simulating geomorphic response to sea level rise and climatic variability in the 21st century. The sediment transport parameters were calibrated using the sediment flux data from 1997 (a relatively wet year) and 2004 (a relatively dry year). The remaining years of data (1998, 2002, 2003) were used for validation. The model represents the inter-annual and annual sediment flux variability, while net sediment import/export is accurately modeled for three of the five years. The use of sediment flux data for calibrating an estuarine geomorphic model guarantees that modeled geomorphic evolution will not exceed the actual supply of sediment from the watershed and seaward sources during the calibration period. Decadal trends in sediment supply (and therefore fluxes) can accumulate to alter decadal geomorphic change. Therefore, simulations of future geomorphic evolution are bolstered by this intermediate calibration step.
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1. Introduction

Modeling estuarine geomorphic evolution addresses concerns that include, but are not limited to, wetland restoration, legacy contaminant resuspension, and estuarine habitat distribution. In light of continued sea level rise and uncertainty of future temperature and precipitation changes, development of appropriate models may assist in preparing for future changes. Sea level rise may increase tidal prism and possibly inundate emergent marshes, thereby altering the sediment transport regime in both channels and fringe areas. Changes in temperature and precipitation will modulate watershed runoff and therefore sediment loads, possibly altering or threatening seaward habitats (Scavia et al., 2002; Pont et al., 2002). Anthropogenic effects on sediment loads have proven to be important (Cappiella et al., 1999); effects from climate

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change may easily be as large. Future water management practices, which may alter the hydrograph more than climate change, will also effect the timing and magnitude of sediment loads to estuaries.

Modeling estuarine sediment transport with a tidal-timescale model typically involves calibrating to the following hierarchy of data: tidal stage, velocity, salinity, and suspended-sediment concentration (SSC) (e.g., McDonald and Cheng, 1997; Lumborg and Pejrup, 2005). Prior efforts in geomorphic (or boundary flux) modeling of estuaries have used these calibrated tidal-timescale models to simulate bed evolution. Lumborg and Pejrup (2005) predict net fluxes over one year using a 20 d time-series of SSC as the validation parameter. Schoellhamer et al. (in press), however, show that calibration to these parameters does not guarantee accuracy in terms of modeling geomorphic evolution. Uncertainty in input parameters can cause bed evolution to adjust in response to erroneous values; this adjustment will not recognized as a ''spin-up'' effect, and the simulation of geomorphic evolution will be compromised. For example, Schoellhamer et al. (in press) show that a 10% error in tidal velocity can cause a bed adjustment that requires 10 years to equilibrate.

Some recent efforts to predict morphological development have used more robust approaches: Douillet et al. (2001) adjusted parameters in order to obtain best qualitative agreement between observations of percent mud on the seabed and simulated deposition; Ouillon et al. (2004) further calibrated the Douillet model using satellite-derived estimates of SSC. This two-step approach provides greater confidence than a single-step approach. Hibma et al. (2003) developed an approach for long-term geomorphic modeling, evaluating the results by comparing the development of morphological features within the model to measured morphological features from two estuaries. The lesson from prior and current efforts is clear: a model must be calibrated and validated to the type of data that will be the final product of the modeling effort.

Two types of data provide the most robust calibration information: frequent bathymetric surveys, and continuous cross-sectional sediment flux data. The former gives a snapshot of bathymetric change between survey dates, though the expense and difficulty of these surveys results in large temporal spacing between surveys (~10 years). This temporal spacing is adequate for decadal-scale geomorphic modeling, but the actual inter-annual and year-to-year mechanics of the sediment transport cannot be verified. In this regard, continuous cross-sectional sediment flux data satisfies multiple goals. The net sediment budget will be correct if the fluxes are modeled correctly, and the tidal and subtidal timescales of sediment transport can be modeled and evaluated. Decadal trends in sediment fluxes will accumulate to alter decadal trends in net erosion and deposition. Therefore, confidence in modeling sediment fluxes generates confidence in modeling net sediment budget trends. However, this is only an intermediate step; the spatial variability of erosion and deposition must still be evaluated using decadal-timescale bathymetric change data.

The two aforementioned data types are available for Suisun Bay, California (Figs. 1 and 2), though their temporal coverage does not overlap. Five bathymetric surveys were performed in Suisun Bay, spanning from 1867 to 1990 (Cappiella et al., 1999). These data show the influence of hydraulic mining on sediment deposition (1867–1887), while the subsequent reduced input of mining debris and decreased freshwater flows (1922–1942) results in net erosion. It would be possible to calibrate a model to these data alone, though the inter-annual and year-to-year sediment transport mechanics could not be evaluated.

An additional data set of cross-sectional sediment flux data, however, is available at the landward and seaward boundaries of Suisun Bay, Mallard Island and Carquinez Strait, respectively (Figs. 1 and 2). These data are available for water years 1997–1998, and 2002–2004. McKee et al. (2006) estimated advective and dispersive loads between

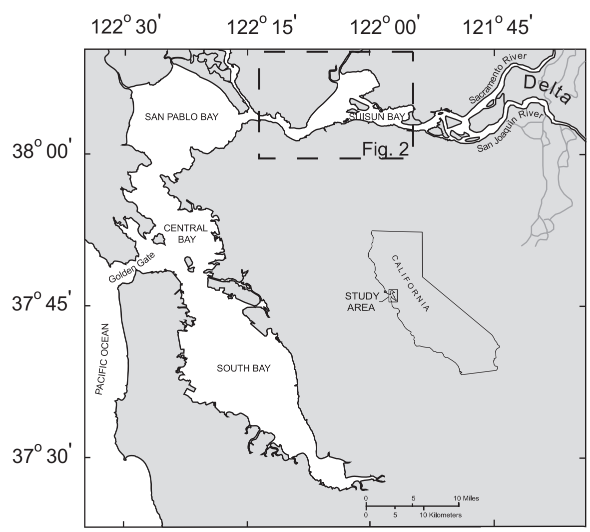

Fig. 1. Area map of San Francisco Bay; Suisun Bay is the landward-most embayment, positioned between the Sacramento/San Joaquin Delta and San Pablo Bay.

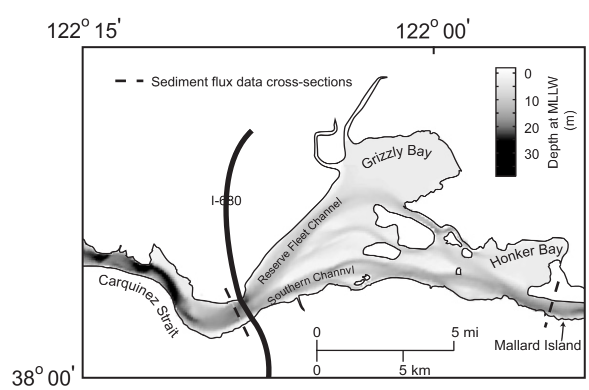

Fig. 2. Detailed map of Suisun Bay; Mallard Island is the landward boundary of Suisun Bay, while Carquinez Strait is the seaward boundary. The model seaward boundary is the left edge of this figure.