Particle Size Distributions of Suspended Sediment in the Sacramento-San Joaquin River Delta

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Particle size distributions of suspended sediment in rivers and estuaries are of interest for a variety of reasons, such as their influence on erosion and deposition processes, their effect on light penetration and primary/secondary aquatic production, and their influence on contaminant adsorption processes. Also, particle size is known to affect the amount of light and sound that is scattered by suspended particles; thus, parameters that are typically used as surrogates for suspended-sediment concentration, such as turbidity and acoustic backscatter, are dependent on particle size distributions. Measurements of *in situ* particle size distributions were made at seven sites in the Sacramento-San Joaquin River Delta as well as along a longitudinal profile of the Sacramento River from Verona (upstream of tidal influence) to Rio Vista (mostly tidal). Size distributions were measured with a laser diffraction particle sizer. At the seven sites, measurements were made from an instrument package deployed on the channel bed. On the Sacramento River, vertical profiles were collected from a stationary boat. Preliminary data analyses indicate a consistent tri-modal size distribution in the Delta, with a narrow peak in the 3-7 micron range, a broad peak centered at 40-50 microns, and a narrow (smaller) peak in the 200-300 micron range. The relative contribution of the different modes varied by site and by position in the tidal cycle. Physical samples collected alongside the *in situ* data suggest that flocculation occurs at all sites; further analysis of samples is ongoing that will further quantify the degree of flocculation. The Sacramento River longitudinal profile documents the flocculation process occurring in the vicinity of the fluvial-tidal transition; as this transition is crossed, the measurements indicate transfer of sediment from the 3-7 micron mode primarily to the 40-50 micron mode. Understanding these flocculation processes is critical for robust numerical modeling of Delta sediment transport.

Keywords: suspended, sediment, particle size, Delta Sacramento River

Wednesday, October 17, 2012: Room 306, Sediment Data and Turbidity in the Bay-Delta System– Order 1

Sacramento-San Joaquin Delta Sediment Budgets Including Regional Transport and Deposition Characteristics for Water Year 2011

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Sediment is recognized as an integral component to the long term management of the highly stressed Sacramento-San Joaquin Delta. By understanding sediment loads, transport, and deposition, we can model contaminant transport, estimate habitat quality, and determine sediment available for wetland restoration in the presence of sea level rise and subsidence. Interest in Delta suspended-sediment transport processes has increased due to recent studies linking fish habitat and movement, particularly Delta smelt, to turbidity. In 2010, we added to an existing network of monitoring sites and began extensive sediment sampling. Our monitoring program is specifically designed to calculate suspended-sediment flux and support numerical modeling efforts. Water year 2011 was above average for both precipitation and flow, though Sacramento River sediment concentrations were low. From 1975 to 2010, suspended-sediment concentrations within the Delta have decreased by approximately 50% and preliminary results show that sediment load to the San Francisco Bay continues to decrease. Similar to previous findings during 1999-2002, in 2011 we found that roughly 75% of the suspended-sediment transported to the Delta by both the Sacramento and San Joaquin Rivers deposits, and the Sacramento River watershed is the primary source of this sediment. In 2011, about 50% of the total sediment deposited was in the central Delta (roughly 800 Kt) and close to 75% of this sediment came from the Sacramento River watershed. The North Delta was the least efficient at trapping sediment, and the Southern Delta was the most efficient at trapping sediment. Though the trap efficiencies for the North and South Delta differed (37% and 62% respectively), the quantity of sediment deposited was similar. Nearly 30% of the total sediment load was transported to the Delta from December 1 to mid-February; nearly 60% of the total load was transported from mid-February to mid-July.

Keywords: sediment flux, turbidity, sediment budget

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Hydraulic Geometry and Bed Material Characteristics of the Sacramento-San Joaquin River Delta

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Hydraulic geometry relations are often useful tools for studying erosion or aggradation processes in a fluvial system, yet are not well quantified in channels affected by both tidal flow and streamflow. In addition, using hydraulic geometry relations in the Sacramento-San Joaquin River Delta presents a particular challenge as the Delta consists of a complex network of channels in which sediment transport pathways may be influenced by the hydraulics at upstream channel bifurcations. Hydraulic geometry, stage and discharge records, and bed-material particle sizes were analyzed at 29 streamgaging stations currently operated in the Delta. The channels at these sites represent a range of widths (45-720 meters), depths (2.5 to 13 meters), median particle sizes (0.025 to 0.68 mm) and varying degrees of influence by tidal flow and streamflow. Characteristics of downstream hydraulic geometry (width, depth and cross-sectional area) were found to have a positive correlation to the magnitude of median streamflow discharge. Cross-sectional area was the characteristic with the highest correlation (Pearson's coefficient of linearity, r, of 0.87). Spatial analysis of median particle size revealed some channels contained bed material which was much different than nearby channels. Some of the variability in the particle size may be related to effects of channel dredging, Delta island flooding, and hydraulic mining. Hydraulic controls at upstream bifurcations may also contribute to some of the variability found between two downstream channels. Preliminary analysis of detailed bed material sampling, bathymetry and transects of streamflow velocity collected at two channel bifurcations in the Sacramento River will also be presented. An understanding of the hydraulics and sediment transport mechanisms in the Delta can be used in the development and support of on-going numerical modeling and provide insight into future effects on erosion and depositional processes in the Delta as a result of sea-level rise or Delta island flooding.

Keywords: bed material, hydraulic geometry, bifurcations

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Development of a Coupled Sediment Transport and Hydrologic (HSPF) Model of the Sacramento River Basin, CA, to Estimate Future Sediment Supply to the Bay-Delta System

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The Computational Assessments of Scenarios of Change for the Delta Ecosystem (CASCaDE II) project requires a better understanding of how potential future changes in the characteristics and climate of watersheds draining into the San Francisco Estuary-Watershed (SFEW) will affect water quality, ecosystem processes, and key species. As part of the cascading set of interconnected components and processes used in CASCaDE II, projections are necessary to estimate future sediment supply from the Sacramento River basin, the source of 80 percent of the sediment contributed to surface water in the SFEW. A sediment transport model using the Hydrological Simulation Program – Fortran (HSPF) is being developed to simulate daily streamflow and suspended-sediment concentrations (SSC) in the Sacramento River and tributaries below the major contributing dams. The HSPF model will provide a direct coupling of current and future climate with the watershed potential sediment sources to estimate sediment supply to the SFEW. Inputs into the HSPF model include precipitation, air temperature, dew point, solar radiation, and wind, as well as watershed parameters such as soil characteristics, land use, geology, channel characteristics, and topography. The HSPF model will be calibrated by using existing SSC and stream discharge data from numerous USGS gages along the Sacramento River and its contributing major tributaries. The HSPF model will initially be calibrated to replicate the declining sediment-supply trend over the past 50 years, and preliminary results will be presented. To predict sediment loads from the minor contributing rivers (San Joaquin, Cosumnes, Mokelumne), an empirical scaling approach will be used to estimate general trends based on model results for the Sacramento River. Results from the HSPF model will provide inputs to the turbidity and geomorphology model, the marsh sustainability model, and the native and alien fishes investigation of the CASCaDE II project.

Keywords: Hydrolologic Modeling, HSPF, Sediment supply, CASCaDE II, Climate Change, SFEW

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Suspended-Sediment Trapping and Pulse Attenuation in the Tidal Reach of Corte Madera Creek, a Tributary of San Francisco Bay

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As sediment supply from the Central Valley to San Francisco Bay decreases, smaller, local tributaries may play increasing roles in sediment supply to this estuary. However, tidal interactions near tributary mouths can affect the magnitude and direction of sediment supply to the estuary. We investigated suspended-sediment dynamics in the tidal reach of Corte Madera Creek, an estuarine tributary of San Francisco Bay, using moored acoustic and optical instruments. Flux of both water and suspended-sediment were calculated from observed water velocity and turbidity for two periods in each of wet and dry seasons during 2010. During wet periods, net suspended-sediment flux was seaward, caused by higher suspended-sediment concentrations (SSC) on ebb tides; tidally-filtered flux was dominated by the advective component. However net seaward flux was only 40% of flux into the tidal reach from the watershed. In contrast, during dry periods, net flux was landward, caused by higher SSC on flood tides; tidally-filtered flux was dominated by the dispersive component. The mechanisms generating this landward flux varied; during summer we attributed wind-wave resuspension in the estuary and subsequent transport on flood tides, whereas during autumn we attributed increased spring tide flood velocity magnitude leading to local resuspension. A quadrant analysis was developed to summarize flux time series by quantifying the relative importance of sediment transport events. These events are categorized by the velocity direction (flood vs. ebb) and the magnitude of concentration relative to tidally-averaged conditions (relatively-turbid vs. relatively-clear). During wet periods, suspended-sediment flux was greatest in magnitude during relatively-turbid ebbs, whereas during dry periods it was greatest in magnitude during relatively-turbid floods. These results suggest that other San Francisco Bay tributaries may alternate seasonally as sediment sinks or sources, leading to the conclusion that previous calculations of sediment supply from local tributaries to the open waters of the estuary are likely overestimates.

Keywords: suspended-sediment transport, sediment supply, sediment flux, local tributary, seasonal variation

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San Francisco Bay Sediment Transport: Comparison of Sediment Supply to San Francisco Bay from Coastal and Sierra Nevada Watersheds

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Information on suspended sediment loads is of paramount importance for managing the world's estuaries. To address this information need, a comprehensive analysis was completed for the San Francisco Bay system by combining a number of formerly disparate data sets. Suspended sediment and optical backscatter measurements near the head of the estuary were used to generate a continuous suspended sediment concentration record. In addition, periodic measurements of velocity and suspended sediment variation in the cross-section were used to validate the use of point samples collected on the edge of the channel for generating loads. Suspended sediment loads were determined by combining daily averaged suspended sediment concentrations with daily flow estimates adjusting for dispersive loads. Sediment loads from the many hundreds of small drainages around the Bay were determined using 235 station years of suspended sediment data covering 38 watershed locations, regression analysis, and simple modeling. Over 16 years, net annual load to the head of the estuary varied from 0.13-2.58 (mean = 0.89) million metric t, or 5.8t/km^2/yr. Small drainages in the nine-county Bay Area discharged between 0.090 and 4.44 (mean = 1.46) million metric t with an average yield of 179 metric t/km^2/yr. Our results indicate that external loads to the Bay are dominated by the many hundreds of urbanized and tectonically active tributaries that drain just 8,125 km^2 adjacent to the Bay and that during only 5 years did sediment loads from the Central Valley likely exceed loads from the sum of the local smaller drainages. If San Francisco Bay is typical of other estuaries in active tectonic or climatically variable coastal regimes, managers responsible for water quality, sediment accumulating in shipping channels, or restoring wetlands in the world's estuaries may need to more carefully account for proximal small urban drainages that may dominate allochthonous sediment supply.

Keywords: variability, suspended sediment, loads, management, central valley, San Francisco Bay

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A Multi-Constituent Approach for Analyzing Sediment Transport in the San Francisco Bay Coastal System

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San Francisco Bay influences so many aspects of life in the area, including the region's financial health. A key factor in this process is maintaining the waterways that provide access to the estuary and this requires an understanding of the regional sediment dynamics. A multi-constituent approach provides a method by which to discern patterns of sediment transport and deposition in the San Francisco Bay coastal system. Analysis of the biological, anthropogenic, and volcanic constituents in >300 samples collected in the region from 1995 to 2010 identifies several patterns: 1) marine organisms (benthic and planktic foraminifera, ostracods, diatoms, and radiolarian) are found in the estuary at the southern end of south bay, commonly in the middle of San Pablo Bay, and occasionally as far east as Honker and Grizzly Bays; 2) estuarine ostracods and benthic foraminifera are present outside the bay on the San Francisco Bar and along the coast; 3) marsh benthic foraminifera and freshwater gastropods and ostracods are present in the middle of the subembayments of the estuary; 4) welding slag and glass microspheres are found far from their presumed origin of docks or roads; and 5) volcanic glass shards are transported from the Great Valley through the delta to all regions of the bay, including the extreme end of south bay and along the coast outside the bay south to Pedro Point. From these data, we can conclude that sediment is transported from the delta to all regions of the bay and out into the offshore realm. The channel in north, central, and south bays, and the Golden Gate, are conduits for sediment movement and sites where scouring occurs. The primary sites of deposition are situated in Honker, Grizzly, and Richardson Bays, along the margins of Suisun, San Pablo and south bays, and eastern central bay.

Keywords: foraminifera, ostracods, diatoms, radiolarian, tephra, sediment constituents, San Francisco Bay

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Synthesis of Bed Characteristics, Geochemical Tracers, in Situ Measurements and Numerical Modeling for Assessing the Provenance of Beach Sand in the San Francisco Bay Coastal System

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Over 150 million m^3 of sand-sized sediment has been eroded during the last half century from the central region of the San Francisco Bay Coastal System. This enormous amount of sand loss may reflect numerous anthropogenic influences, such as watershed damming, bay-fill development, aggregate mining, and deep-water dredge disposal. This reduction in sediment supply is thought to be linked to recent wide-spread erosion of adjacent beaches, wetlands, and submarine environments. A unique, multi-faceted, multi-disciplinary provenance study was performed to definitively establish the primary sources, sinks, and transport pathways of beach-sized sand in the region, thereby identifying the activities and processes that directly limit the supply of sand to the outer coast. This integrative program is based on comprehensive surficial sediment sampling of the San Francisco Bay Coastal System, including the seabed, Bay floor, area beaches, adjacent rock units, and all major drainages. Analyses of sample morphometrics and biological composition (e.g., Foraminifera) were then integrated with a suite of tracers including $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ isotopes, rare earth elements, semi-quantitative X-ray diffraction mineralogy, and heavy minerals, and further with process-based numerical modeling, in-situ current measurements, and bedform asymmetry to robustly determine the provenance of sand in the region.

Keywords: provenance; bedforms; sediment transport; isotopes; foraminifera; heavy minerals; numerical modeling

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Sediment Dynamics in the Shallows of San Francisco Bay

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Estuarine shallows retain fine sediments, and serve as a source of sediments for intertidal mudflats and marshes. The ongoing large-scale restoration of diked-off, subsided wetlands adjacent to San Francisco Bay relies largely on sediment supplied from the Bay by natural processes. These same processes will be critical in sustaining marshes as sea level rises. The details of how wind, waves, and tidal currents interact to transport sediment between channels, shallows, mudflats, and marshes are poorly understood, largely due to a historical lack of data from shallow environments. In recent years we have collected current, wave, and suspended sediment data to investigate sediment resuspension and transport in shallow regions of South Bay, Central Bay, and San Pablo Bay. This talk will summarize our findings on transport between the shallows and the channel, transport between subtidal and intertidal flats, and the evolution of wind waves over shallows. As expected, wind-wave driven resuspension produced the greatest concentrations and fluxes of suspended sediment. However, the direction of suspended sediment flux (SSF) during wind events was variable. The South Bay data show that SSF in the shallows was directed landward during moderate wind events, but towards the channel during strong wind events. The San Pablo Bay data show that SSF during wind events was directed landward at an intertidal site, and towards the channel at subtidal sites. Concentrations at the intertidal site were greater than expected for a given wave shear stress, largely due to the shallow water depths which limit the volume available for dilution. The shallow depths also limit the speed of tidal currents and thus transport. Data sets such as these are essential for calibrating and testing numerical models of sediment transport in San Francisco Bay, which are used to guide habitat restoration and regional sediment management.

Keywords: sediment transport, shallows, resuspension, wetlands, restoration

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Influence of History and Environment on the Sediment Dynamics of Intertidal Flats

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The intertidal flats provide important, and sometimes critical, habitats for benthic communities, fish, birds, and mammals in San Francisco Bay. Additionally, these generally depositional intertidal flats can act as reservoirs for sediment bound contaminants from both historic and ongoing sources. Development of a deeper understanding of the processes governing the morphology and character of the intertidal flats presents an important problem to scientists and engineers for the enhancement of habitat and reduction of potential ecosystem and human health risks. The stability and equilibrium of the flats are constantly shifting due the influence of a wide range of physical and biological factors (Friedrichs and Perry 2001). Consequently, a large body of scientific study has been devoted to both the physical and biological factors. Physically, intertidal flats are typically comprised of cohesive sediment mixtures in coastal and estuarine environments. The lack of solid understanding of the processes controlling the erosion, transport, and subsequent deposition of cohesive sediments provides a significant stumbling block in our ability to quantitatively predict the behavior of systems dominated by cohesive sediments. The physical characteristics of the sediments in conjunction with a general system understanding can often guide a solid description of the sediment dynamics. This study outlines the merging of long-term morphologic data with measurements of sediment erosion rates and modeling to develop just such an understanding of intertidal flats in three distinct environments in South San Francisco Bay, California.

Keywords: intertidal, mudflat, sediment transport, erosion, deposition, morphology, stability modeling

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Use of Scour Monitoring Data for Sediment Budget Analysis and Model Validation in the Delta

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The California State Department of Water Resources (DWR) Scour Monitoring Program collects semi-annual cross-section data throughout the Sacramento-San Joaquin Delta. Begun in 1969, the program has expanded to include 112 cross-section sites today. These cross-section data provide a real-world basis to describe long-term sediment budget trends in Delta channels and characterize morphologic adjustments over time. A section of the Middle River and adjacent channels in the south Delta were selected to analyze available scour monitoring data over a 15 year period from 1990 to 2004. Year-to-year trends often showed significant variability, reflecting seasonal hydrology or short-term effects such as levee modifications, dredging, or specific events. Ordinary least-squares regression of the 15-year dataset showed a net decline in channel depth and cross-section area for the majority of sites selected. Sediment budget calculations using the end-area method show a slight trend of net sediment deposition on the Middle River for the 1990 to 2004 period, in agreement with analyses of long-term sediment transport records (NHC 2003). Bed material samples and recent application of project-specific multibeam bathymetric surveys by the DWR provide supplemental information to characterize morphologic change and sediment transport conditions such as sand dune migration. Sediment budget estimates from long-term cross-section records, coupled with bed material characterization, provide a real-world basis for the calibration and validation of long-term numerical model simulations of sediment transport rates and budgets in the Delta.

Keywords: delta sediment budgets, morphologic change, model validation

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Tracking Sediments through the Bay-Delta System over a Water Year with a 2D Process Based Odel (D-Flow FM)

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The Sacramento-San Joaquin Delta and Watershed is the main source of sediment to San Francisco Bay. In the first part of the 20th century several hydraulic structures were built in the catchment trapping sediment upstream. Wright and Schoellhamer (2004) show that from 1957 to 2001 the sediment load carried to San Francisco bay has halved. The decay of suspended sediment in the bay prevents marsh development with impact on local ecosystems.

In this study, we couple the Delta and Bay in a unique model network (the Delta-Bay model). This coupling allows tracking of sediment from Sacramento to the Bay and through the Golden Gate, making it possible to identify dispersion and deposition areas. The model was built in two steps. First, an unstructured, process-based model (D-Flow Flexible Mesh developed by Deltares) was used to simulate the hydrodynamics of the area on a detailed, 64000-node mesh (10-200m mesh length scale). Secondly, Delft-WAQ, a post-processing tool from Deltares was used to simulate the suspended sediment concentration (SSC) based on the hydrodynamic output by D-Flow FM.

The results show that most of the sediment that deposits in the Delta comes from the Sacramento River. It also shows that subsequent high river flows (over several years) ultimately transport the sediment towards the Bay. Sensitivity analysis includes different mud characteristics as well as varying river discharge and pumping scenarios (water export towards Southern California). Sensitivity analysis shows that suspended sediment concentration in the Delta-Bay system is more sensitive to discharge changes of Sacramento River than changes in pumping volume at Clifton Court.

Keywords: Numerical Modeling, Suspended Sediment, Unstructured Mesh

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Validation of 3D Sediment Transport Modeling in the Delta

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A 3-dimensional hydrodynamic and sediment transport model of the Sacramento-San Joaquin Delta to was validated for use in the U.S. Army Corps of Engineers CALFED Levee Stability Program and Delta Study.

The model uses the Environmental Fluid Dynamics Code (EFDC). The model grid includes Yolo Bypass, the Sacramento River to Verona, approximately ten miles of the American River, the San Joaquin River system to Vernalis, and Suisun Bay to the Carquinez Strait. Physical processes simulated in the model include hydrodynamics governed by currents and wind waves, temperature, salinity, and cohesive and non-cohesive sediment transport, deposition, and erosion.

The model was adjusted and validated to observed data from the years 2003 and 2004. It predicts TSS with a residual of less than a standard factor of 2 for all locations except one. The model slightly under predicts the total suspended solids (TSS) concentrations in the model domain – a model average of 49mg/l compared with 53 mg/l observed. The model under-predicts TSS at several locations due to a lack of the sediment bed characterization data and phenomena which are not modeled by EFDC, such as the re-suspension process caused by ship traffic. However, the model captures the major processes matching the magnitudes and timing of the observed TSS data.

In the main channels TSS is strongly governed by the re-suspension induced by the interaction of the tidal currents and fresh water flows. Off the main channels and in the shallow bay area, the sediment re-suspension process caused by wind waves becomes important, The sensitivity of the model results on TSS to the model parameters and inputs shows it to be most sensitive to the model parameters related to there-suspension processes, either driven by wind wave or by currents.

Keywords: Sediment Transport, 3D Hydrodynamics, validation tss efdc efdc_explorer resuspension wind

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Numerical Simulations of First Flush Sediment Dispersal throughout the Sacramento-San Joaquin Delta and San Francisco Bay

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The UnTRIM San Francisco Bay-Delta Model has been coupled to the SWAN wave and SediMorph sediment models to simulate three-dimensional sediment transport throughout the San Francisco Bay and Sacramento-San Joaquin Delta. The seabed of the Bay and Delta are initialized using observed surface grain size distributions, and sediment is supplied to the Delta from the Sacramento, San Joaquin, Cosumnes and Mokelumne Rivers and the Yolo Bypass. Both the seabed and river supplied sediment undergo erosion caused by waves and currents, deposition, and three-dimensional advective transport and mixing within the numerical modeling system. This numerical modeling system is used to simulate the sediment transport of a first flush sediment pulse from the riverine sources to locations of sediment deposition within the San Francisco Bay and Sacramento-San Joaquin Delta.

The first flush sediment is distributed throughout the San Francisco Bay. Model results highlight that more first flush sediment is deposited on the shallow shoals than in the deeper channel regions of Suisun and San Pablo Bays, following the conceptual model proposed by Krone (1979). After the first flush sediment pulse, the deposited sediment is resuspended by waves and currents and transported toward the Pacific Ocean and the South Bay. This sediment resuspension and dispersal is strongly tied to spring tides and wind wave events.

Keywords: First Flush, Sediment Transport, UnTRIM, SediMorph, SWAN, Numerical Modeling

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Three-Dimensional Coupled Wind-Wave and Mud Suspension Modeling in San Francisco Bay

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A numerical model is presented to simulate transport and suspension of cohesive sediments in San Francisco Bay. We employ the unstructured-grid SUNTANS model for hydrodynamics and within this model we implement a multiclass sediment transport model and a wind-wave model to calculate phase-averaged properties of high-frequency waves. Hydrodynamics is calculated by solving the phase-averaged Navier-Stokes equations that are coupled to the waves through the radiation stress. Transport of cohesive micro and macro flocs is computed with the advection-diffusion equation with a settling velocity for each size class. Mud suspension is computed with a mud model that interacts with a multilayer bed model that accounts for limited bed erodibility due to consolidation. Combined with a bedform model that allows parameterization of bedform-induced form drag, this allows for parameterization of wave dissipation mechanisms due to a variety of bed properties, which is of critical importance for modeling shallow water waves in estuarine systems. The model is calibrated against field observations in South San Francisco Bay, and we assess the relative importance of tidal and wind forcing on mud suspension as well as the influence of the mud suspension on the wave field.

Keywords: Sediment transport modeling

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