SACRAMENTO RIVER SEDIMENT SOURCES, TRANSPORT, AND SUPPLY TO THE DELTA

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The Sacramento River is the primary source of sediment to the Delta. Recent studies indicate that suspended sediment is an important indicator of habitat quality for endangered native fish. Also, previous work documented decreases in sediment supply from the Sacramento over the past half century in response to anthropogenic impacts. Predictions of future sediment supply in response to climate and water management scenarios require an understanding of sediment sources and transport in the watershed. To this end, this study reviews sediment data collected during 1979 and 1980 when an intensive monitoring program existed in the Sacramento Valley. These data serve to illustrate sources and transport processing during below normal (1979) and above normal (1980) hydrologic conditions. For both years, the primary source of sediment was the upper reaches between Keswick Dam and Hamilton City. In 1979, spills to Sutter and Yolo bypasses were minimal such that the sediment generated in the upper reaches was transported downstream in the main channel to the Delta. Though the Feather River was a significant source of water, its sediment supply was relatively small compared to the supply from the upper reaches (for 1979 and 1980). During 1980, substantial spills occurred to the bypasses and this substantially affected sediment (and water) routing in the system. Sediment loads decreased substantially in the middle reaches as water and sediment were spilled to Sutter bypass. Above Verona, Sutter bypass and the Feather join the Sacramento and can spill into Yolo bypass. In 1980, this resulted in a large increase in downstream Sacramento flows but only a modest increase in sediment loads because of the low sediment load of the Feather as well as deposition in Sutter bypass. Limited data exist for sediment loads in the Yolo bypass and lower Sacramento, and this remains an area for further study.

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AN OBSERVED STEP CHANGE IN DELTA TURBIDITY FOLLOWING 1982-1983 EL NINO FLOODS

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Sediment transport influences the geomorphology, biogeochemical cycling, pollutant load, and ecology of river deltas and estuaries. In the Sacramento-San Joaquin Delta, turbidity is largely considered a surrogate of suspended sediment concentration, and has been declining over the past 30 years. This has contributed to dramatic changes in the ecology of the Delta and to the decline of the endemic and endangered delta smelt. The declining turbidity trend in the Delta has been attributed to reduced sediment inputs and expansion of invasive submerged aquatic vegetation. In this study, we analyzed historic monthly turbidity records collected by the California Department of Water Resources Environmental Monitoring Program from 1975-2008. We investigated structural changes in the turbidity trend, and identified a significant step decrease in turbidity after the beginning of the 1984 water year at nine different sites within the Delta. This significant decrease in Delta turbidity appears to have been caused by the combination of large El-Nino driven winter floods from both the San Joaquin and Sacramento Rivers in 1982-1983 and the high inflows throughout the summer. We suggest that these extended high flow events flushed the erodible sediment pool from the Delta into the San Francisco Bay. This event has left the Delta in its current, low-turbidity state. Another study found that a step decrease in suspended sediment concentration in San Francisco Bay in 1999 may have been caused by depletion of erodible sediment. This indicates that depletion of erodible sediment may have progressed downstream and, if the erodible sediment pools were created by hydraulic mining in the late 1800s, sedimentation in the estuary has largely recovered from hydraulic mining.

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COMPREHENSIVE GEOMORPHIC AND SEDIMENTATION ANALYSES OF LOWER SACRAMENTO RIVER SHOWS PROMISE FOR SEDIMENT BUDGET MODELING OF THE DELTA

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The sediment budget of the Sacramento and San Joaquin Delta system is required for assessing future adjustments in the morphology of this complex landscape of channels, floodplains, and islands. To better understand implications of the sediment budget on morphology, comparisons of the sediment budget with observed morphological adjustments such as bankline adjustment, channel bed change, and the feedback to channel hydraulics is required to develop reliable forecasting tools for predicting future changes to the sediment budget. Northwest Hydraulic Consultants (NHC) completed a sediment budget analysis of the Delta as part of a comprehensive analysis for subsidence management alternatives on Delta islands (Shvidchenko et al., 2004). This analysis included estimates of both bed material and suspended wash load, and identified pathways of sediment inflow, storage, and outflow. More recently, NHC undertook a systematic analysis of the sediment transport and channel morphology of the Sacramento River system for the Army Corps of Engineers. This study collected and reviewed available historic and present-day data related to geomorphology and sediment transport of the Sacramento River system and assessed implications of channel evolution trends and sediment transport regime on the river as well as sediment delivery to the Delta. A 1-dimensional numerical model of the lower Sacramento River was developed that includes sediment routings through the river channel as well as inflows and diversions to the river from the flood bypass systems. The verified model provides very good agreement to measured sediment discharge loads, bed material gradations, stage-discharge rating shifts, and measured bathymetric changes. The computed sediment yield at the Freeport gaging station shows an excellent correspondence between computed and measured sediment discharge for the 1997-2008 time period. Combining NHC's Delta sediment budget with this new tool provides a means for linking implications of future river management activities on Delta sedimentation dynamics.

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MODEL BASED INTERPRETATION OF SEDIMENT CONCENTRATION AND VERTICAL FLUX MEASUREMENTS IN THE SHOALS OF SOUTH SAN FRANCISCO BAY

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Our study focused on the driving factors of sediment resuspension and settling dynamics in the shoals of South San Francisco Bay. We deployed an array of stations in spring and fall 2009 at a shallow field site (2.19-2.59 MLLW) to measure horizontal and vertical gradients of turbidity together with fluid flow, turbulence, and pressure across the shoal-channel transition. Flow velocities, Reynolds stress, wave properties, sediment concentration and turbulent sediment fluxes were measured using ADVs. We developed a simple 1-D dispersion-settling model to interpret the observed sediment concentrations and fluxes. We assumed the existence of two sediment fractions with differing settling behavior. Sediment resuspension into the water column was described as a linear function of the observed sediment flux. Our model study showed that the observed concentrations were best described by a fast settling fraction with a constant settling velocity ws of 0.003 ms-1 attributed to coarse particles and a slowly settling fraction with a concentration dependent settling velocity ws=k*CSed with k = $8*10^{-6}$ m^4 $s^{-1}g^{-1}$attributed to fine particles, suggesting a coagulation mechanism for the settling of the latter fraction. Modeled sediment concentration profiles showed that the fine sediment fraction can contribute over 70% of the sediment mass. Still, steeper gradients in the profiles of the coarse particles show that these particles are the main contributors to the measured sediment flux. Understanding the sediment transport in the South San Francisco Bay is of crucial importance for the prediction of contaminant and nutrient dynamics as well as predicting the formation and erosion of wetlands and intertidal mudflats. Our study highlights the importance of differing particle fractions in the sediment dynamics of the Bay, especially since these fractions differ in residence time in the water column. The presented results also provide a good starting point for a fully coupled sediment bed-water column model.

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UNCERTAINTY ANALYSIS FOR GEOMORPHIC MODELING

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The prediction of changes in long-term sedimentation (decadal time scale) are necessary if the impacts of projects that affect sedimentation in San Francisco Bay and Delta are to be adequately estimated. However, the prediction of sedimentation over these time scales is subject to a large amount of uncertainty. Causes of the uncertainty include unknown inputs, model approximations, errors in model parameters and method adopted for geomorphic analysis and the natural variability in sedimentation. This presentation presents a method for quantifying the uncertainty. The method is then applied to a proposed project in South San Francisco Bay as an example. An important component of estimating the uncertainty in the prediction of future long term sedimentation is to estimate the variance in the random error associated with the future prediction, which is assumed to be equal to the variance of the actual prediction of sedimentation. This value is estimated by dividing the simulation area in contiguous zones with similar habitat type, environmental conditions, and project impacts. The variance in the error is then estimated from point and average estimates of error within each zone based on hindcast simulations. The variance associated with project impacts can then be estimated based on the variance in the error in estimating future sedimentation and the expected correlation between no action and project conditions. An example application of the method is applied to a proposed projected in the South Bay. The results include a map of the Bay showing the expected changes in sedimentation, the forecast uncertainty and the coefficient of variation of the forecast error.

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THREE-DIMENSIONAL MODELING OF SEDIMENT DYNAMICS IN SAN FRANCISCO BAY USING THE SUNTANS MODEL

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We employ the unstructured-grid SUNTANS model to simulate hydrodynamics and sediment transport in San Francisco Bay. The domain extends offshore of the Golden Gate by 25 km where sea-surface tidal constituents at Point Reyes are imposed, and the Delta is modeled as a "false Delta" with two rectangular boxes at the confluence of the Sacramento and San Joaquin Rivers. With an average horizontal resolution of 200 m and a minimum vertical resolution of 25 cm, the model is calibrated to produce accurate predictions of sea-surface height, salinity, and depth-averaged currents throughout the Bay. Cohesive suspended sediment transport is modeled with the transport equation with a settling term that accounts for flocculation using results from observations, and this suspended sediment interacts with a multilayer bed model with five layers ranging in thickness from 25 mm to 1 m. A phase-averaged wave model is employed to incorporate the effects of wind-wave induced sediment resuspension. We demonstrate the behavior of the combined hydrodynamics-sediment-wave model and focus on comparisons to observations in South Bay, and we demonstrate the sensitivity of the results to the relative effects of tides and wind-waves.

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SEDIMENT TRANSPORT AND VEGETATION GROWTH SIMULATION ON THE SAN JOAQUIN RIVER

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Sedimentation and River Hydraulics – One Dimension (SRH-1D) is a one dimensional hydraulic and sediment model used to simulate water surface profiles, sediment transport rates, and erosion and deposition within rivers and canals. There is also a vegetation module that has been built into SRH-1D and this version is called SRH-1DV. The vegetation module tracks the establishment, growth, and survival of various riparian species. The model parameterizes the establishment, growth, and morality using available information for each species. In addition, a companion paper in this conference describes laboratory measurements of cottonwood establishment used to parameterize the model. SRH-1DV has been applied to the San Joaquin River and the flood bypasses from Friant Dam to the confluence with the Merced River to predict future erosion and deposition with and without the San Joaquin River Restoration Program (SJRRP). The model requires several inputs. Cross section information was taken from existing HEC-RAS models of the system. Bed material data was collected from field samples collected throughout the river and bypass system. The daily flows used in the simulations were generated by CALSIM II and a daily time step model. We used the simulated daily flows under with and without SJRRP and we also simulated the erosion and deposition using historical stream gage data. Some of the main concerns of the project include improving and maintaining anadromous fish habitat below Friant Dam and maintaining flood capacity in the project reaches. To this end, we analyzed the mobilization of gravel, analyzed simulated changes to the bed elevations, and also to the riparian vegetation. The reach downstream of Friant is primarily gravel and cobble and we analyzed whether project flows will be able to mobilize this gravel to maintain salmon spawning beds. This reach is already heavily vegetation and does not have significant levee systems. Further downstream, the San Joaquin transitions to a sand bed river and several reaches are without surface water the majority of the year. There is currently little vegetation and the levee system is already stressed. The resupply of base flow to these dry reaches will potentially cause erosion or deposition and increase riparian vegetation density. We use SRH-1DV to assess the erosion or deposition in these reaches and also additional vegetation growth under the San Joaquin River Restoration Project.

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TECHNICAL DETAILS OF THE DEVELOPMENT OF A SEDIMENT-TRANSPORT MODULE FOR DSM2

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This presentation describes the development of a one-dimensional Sediment and Transport Module (STM) for the Delta Simulation Model 2. STM is a general transport model for conservative and non-conservative constituents with special focus on sediment transport. The module includes cohesive and non-cohesive sediment transport in tidal channel networks. Both suspended sediment and bed load are simulated in the module. STM uses a second order accurate, finite volume numerical solution. To verify that components of the model are coded properly, a companion testing code has been developed.

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EXPERIENCE MODELING TURBIDITY IN THE SACRAMENTO-SAN JOAQUIN DELTA FOR THE 2009-2010 WINTER SEASON

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With funding from the Metropolitan Water District of Southern California (MWD) and in collaboration with DWR Operations and Maintenance (O&M) staff, Resource Management Associates (RMA) has developed a 2-D turbidity modeling protocol for short-term forecasting. Starting in December 2009, many new real-time turbidity monitoring stations became available in the Delta, providing a rich data set for developing model boundary conditions and evaluating the performance of turbidity predictions. Using O&M's DSM2 flow and salinity forecast boundary conditions as a starting point, flow boundary conditions for the Sacramento and San Joaquin Rivers and for the Yolo boundary were refined using forecast conditions from the California-Nevada River Forecasting Center (CNRFC). A simple methodology was developed for forecasting 50% and 90% exceedance values for turbidity boundary conditions at the Sacramento and San Joaquin boundaries. The initial application of a simple turbidity model based on exponential decay gives reasonable results throughout much of the Delta, however, comparison of model results to the extensive observed data set reveals several factors that should be included in a more comprehensive model including: wind-driven resuspension in open water areas; turbidity loading from local rain; ungaged inflows particularly in the Eastern Delta; and settling and resuspension in channels with low net velocity. Overall, the results indicate that measured turbidity will be better approximated by a full suspended sediment model with meteorological inputs for local precipitation and wind, particularly if flow can be measured more accurately during and shortly after storm events.

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SEDIMENT MODELING FOR THE DELTA ISLANDS AND LEVEES FEASIBILITY STUDY

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The Sacramento – San Joaquin River Delta consists of a 700-mile network of controlled channels, 1,100 miles of levees, and 70-plus islands, most of which are well below sea level. The current system is a patchwork of projects implemented over the last 150 years primarily for land reclamation, flood control, navigation, and water delivery. Delta water supports $400 billon of the state economy, supplies two-thirds of the households, and provides habitat for many species. The Delta as a vital economic and ecologic resource for the residents of California and the nation is at risk. Continued development, changes in conveyance, subsidence, invasive species, seismic risk and weather/climate risks are likely going to challenge the system even further. While many models have been used in the system the 3-dimensional Environmental Fluid Dynamics Code (EFDC) has been chosen for this work. The 3-D hydrodynamic EFDC model will provide the necessary detailed predictions of water level and velocity for flooding analyses and all constituent transport processes from salinity to sediment to dissolved oxygen for existing conditions and predicted future scenarios, including plan alternatives. The numerical model has been designed to represent the major hydrodynamic processes, transport pathways and fate of nutrients, sediments, carbon and contaminants in surface waters and is capable of capturing subtle circulation patterns such as residual flows and density currents that are essential to representative transport of dissolved constituents and suspended materials. The purpose of the work described is to support the Delta Islands and Levees Feasibility Study (DILFS) and CALFED, specifically through the modeling of sediment transport, deposition and erosion. It is generally understood that sediment in the Delta can be beneficial, as when it nourishes wetlands and provides habitat for aquatic species that prefer turbid water or a specific substrate. It can have adverse effects when it produces a hostile habitat for aquatic species or clogs channels and outlet works that cause significant expense in the dredging of navigation channels, ports, and terminals. The EFDC suite of models will be used to support the development of water resource management plans for the Sacramento-San Joaquin Delta and provide managers with quantitative evaluations and comparisons of the relative effectiveness of alternative plans to achieve the objectives in relation to known Delta issues related to water supply, water quality, flooding, navigation, recreation, sedimentation, ecosystem health, economics, and aesthetics.

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A RE-ASSESSMENT OF THE HISTORIC CHANGES IN SEDIMENT FLOWS INTO SAN FRANCISCO BAY

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There is good deal of interest in understanding how sediment flows into San Francisco Bay have changed relative to historic and natural conditions. These changes can affect dredging needs, erosion rates, the re-suspension of buried contaminants, tidal marsh restoration efforts and the capacity of the Bay to support oyster and eelgrass beds. They also provide a benchmark for assessing projected impacts from climate change. The Bay sediment literature uniformly quotes estimates from Grove Karl Gilbert's 1917 monograph on hydraulic mining debris as the baseline for natural (pre-1850) and peak historic (roughly the last half of the 19th century) sediment flows into the Bay. However, a review of Gilbert's sediment budget model reveals that his estimates have been misquoted since he does not actually provide a value for historic sediment inflow to the Bay, nor can a specific value be calculated from his data (though rough upper and lower bounds can be determined). More critically, however, incorrect values for bulk sediment density have been used to convert Gilbert's sediment volume estimates to mass units for comparison with modern sediment flow measurements, thereby substantially understating Gilbert's sediment flow estimates, possibly by a factor of 3-5. Overall, the baseline estimates of natural and peak historic sediment inflows are much higher and more uncertain than recent literature has indicated, which greatly alters our perception of both where we are today and where we are headed relative to baseline conditions. This in turn affects our understanding of how shifts in sediment inflows due to dams, diversions, channel alterations, land use, climate change or other anthropogenic factors may affect shoreline erosion, the ecosystem's exposure to legacy contaminants, and the potential to achieve certain types of environmental restoration or enhancement.

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ENVIRONMENTAL IMPACTS AND REGULATORY IMPLICATIONS OF THE APPARENT EXPULSION OF THE HYDRAULIC MINING ERA PULSE OF MERCURY LADEN SEDIMENT FROM SAN FRANCISCO BAY

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Problem Statement: Over several decades, a significant reduction in the sediment load entering San Francisco Bay from the Delta and its major river tributaries has spurred an increase in the resuspension of the Bay’s erodible sediment pool allowing suspended sediment concentrations to maintain equilibrium. Recently published data (NOAA 2009) suggest that the erodible sediment pool, consisting primarily of shoaled sediments from Gold Rush era hydraullic mining, may have been essentially depleted. If ambient mercury concentrations in Bay sediments have been reduced with the depletion of mining related sediments, how will policy measures aimed at reducing levels of mercury in San Fracisco Bay (i.e. mercury TMDL) be impacted? Approach: Recent deepening the Oakland Harbor navigation channels to pre-industrial sediment strata, make this location an ideal for assessing the trend in mercury concentrations in newly shoaled sediments in San Francisco Bay. Sediment samples from the Oakland Harbor were collected prior to maintenance dredging every year since the deepening project was completed and analyzed for mercury. Results were compared to historic levels documented for Oakland Harbor and other regions within the Bay. Results: The results of this investigation show that mercury present sediments newly accreted in Oalkand Harbor every year since the navigation channel was deepened are consistent with pre-industrial, background concentrations (~0.23 mg/kg). Conclusions: Under the Clean Water Act's Section 303d, the San Francisco Bay was deemed impaired for mercury, and a Total Maximum Daily Load (TMDL) for this contaminant was developed and amended to the San Francisco Bay Regional Water Quality Control Board's Water Quality Control Plan. A significant reduction in ambient San Francisco Bay mercury sediment concentrations associated with the apparent dramatic depletion in mining related sediments may imply that a substanitial reduction in the total Bay Area mercury load, and warrant a modification to the mercury TMDL implementation plan. This is especially true for Bay Area dredge permit applicants because the TMDL currently prohibits discharge of dredged material to the Bay's authorized aquatic disposal sites unless the material exhibits concentrations lower than the current ambient sediment mecury concentration (0.53 mg/kg).

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NEW ESTIMATES OF SUSPENDED SEDIMENT LOADS TO SAN FRANCISCO BAY

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Information on suspended sediment loads is of paramount importance for managing the Bay-Delta due to associated degradation of water and sediment quality, recreation amenities, native species habitat, and disruption of commercial shipping operations. Yet we still have limited understanding of suspended sediment and contaminant loads in various components of the ecosystem. Research in the 1970s and 80s provided evidence that approximately 80% of the sediment supply to the Bay was from the Central Valley. Since then, sediment loads from the Central Valley have trended downwards, a premise promulgated by Krone (1996) in Hollibaugh (Ed.) San Francisco Bay: The Ecosystem and confirmed by Wright and Schoellhamer (2004) San Francisco Estuary and Watershed Science Journal. Based on point and cross section measurements of turbidity and suspended sediment concentrations at Mallard Island, we presented evidence that the average annual suspended sediment load passing from the Central Valley through the Delta past Mallard Island is now 1 million metric t (McKee et al. 2006: Journal of Hydrology). Recently we completed a new evaluation of suspended sediment loads in small tributaries of the nine county Bay Area using a combination of 177 station years of sediment data covering 29 watersheds, regression analysis, and simple modeling (Lewicki and McKee, 2009: SFEI technical report). Along with updated estimates of Delta loads, this research shows that an estimated 1.3 million metric t is supplied from the tributaries of the nine-county Bay Area, and that the balance is tipped even more than Krone had predicted. Our results imply that the Bay suspended sediment budget is now dominated by supply of fine more highly contaminated sediment from urbanized nine-county Bay Area tributaries. Managers responsible for sediment accumulating in shipping channels and restoring wetlands may need to more carefully account for proximity to urban tributaries and contaminant sources.

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SUSPENDED-SEDIMENT FLUX IN THE SHALLOWS OF SOUTH SAN FRANCISCO BAY

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The shallows of San Francisco Bay retain fine sediments, and are thought to serve as a source of sediments for intertidal mudflats and marshes. Thus sediment transport in the shallows and shoal-channel exchange are important components of the Bay sediment budget. We evaluated near-bed suspended-sediment flux (SSF) at two sites in the eastern shallows of South San Francisco Bay from February 24 to March 16 (spring) and September 9 to October 6, 2009 (fall). The sites were 0.3 km (ShN) and 1.3 km (Be) from the channel edge, at depths of 2.6 m and 2.2 m MLLW. During both deployments and at both sites, the along-channel component of SSF was directed down-estuary during calm periods and up-estuary during windy periods. The up-estuary flux was produced by a correlation of higher suspended-sediment concentration (SSC) with flood tides, due to enhanced wind-wave resuspension at low water and vertical mixing by the ensuing flood-tide currents. SSF during two intense wind events at the end of the fall deployment (wave heights > 0.5 m) was an order of magnitude greater than at any other time during the study. As a result, cumulative flux in fall was directed up-estuary, whereas in spring it was down-estuary and much lower in magnitude. Cumulative cross-shore SSF in the spring was directed toward the channel at ShN, but was toward shore and lower in magnitude at Be. During the fall, cross-channel SSF was directed toward the channel at both sites and was greater at ShN than Be, although the total magnitude of cumulative SSF was much lower at ShN than Be. The spatial variation in cross-channel SSF during both deployments indicates net erosion and transport into the channel, and suggests that the region of the shoals adjacent to the channel does not supply sediment to adjacent marshes.

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MEASUREMENTS OF WATER COLUMN AND SEDIMENT BED INTERACTIONS IN THE SOUTH SAN FRANCISCO BAY ESTUARY

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Sediments in the South San Francisco Bay in the bed and in the water column are composed primarily of fine cohesive sediments which are known to be contaminated with a number of new and legacy contaminants. Changes to the South Bay environment, including sea level rise and habitat restoration, have increased concerns that the South Bay may be erosive, introducing additional contaminants into the South Bay ecosystem. Further understanding of the processes that determine the behavior of fine sediments found in the water column and in the bed are needed to evaluate and model how the South Bay will respond to the changing environment. A three week instrument deployment was undertaken in the South Bay to better understand shoal-channel sediment processes at multiple scales. Instruments deployed at ten stations covering roughly two square kilometers measured water velocities, suspended sediment concentrations, salinity and temperature at hourly or shorter intervals. Measurements of the particle size distribution were also made at one location every 12 minutes for the first five days and sediment cores were collected at the beginning and end of the deployment from two locations. From these measurements turbulence and other parameters have also been calculated. Measurements of suspended sediment concentrations during the deployment usually were in the range of 5-50 mg/L on the shoals, with the lowest concentrations observed during spring tides. Episodic events driven by wind waves created peaks around 100 mg/L. Analysis of sediment cores indicated disturbances to the sediment bed of less than 1 cm. Flood tide resuspension of sediments were affected by several factors including strength, duration and direction of the flood tides. Second resuspension events were observed during ebb flood tides, subject to the same factors. Particle size distributions measured during the second resuspension event were different from those measured during the primary resuspension event.

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