Remote Sensing to Infer Surface SPM in San Francisco Bay

Joseph H Adelson*, The Bob and Norma Street Environmental Fluid Mechanics Laboratory (BNSEFML), Dept. of Civil and Env. Engineering, Stanford University, joe.adelson@gmail.com
Nathan Kau, BNSEFML, Dept. of Civil and Env. Engineering, Stanford University, nathankau@gmail.com
Oliver B Fringer, BNSEFML, Dept. of Civil and Env. Engineering, Stanford University, ofringer@gmail.com

Multi-spectral satellite images of the San Francisco Bay region have the potential to provide broad spatial information about biological productivity, water quality, suspended particulate matter (SPM), and light attenuation. While satellite remote sensing algorithms are well established for quantification of sea-surface temperature and biological productivity in the ocean, there is currently very little remote sensing work designed to predict SPM in estuaries like San Francisco Bay. As part of a project in which we seek to deploy UAVs with high-resolution, multispectral cameras to measure surface SPM, we have developed algorithms to infer surface SPM in San Francisco Bay from Landsat Enhanced Thematic Mapper Plus data and validated the results with USGS Polaris cruise measurements. We tested several regression algorithms including: linear regression, Huber regression, and an artificial neural network. Neural networks are a class of machine learning algorithms well suited to non-linear statistical modeling. Our calibrated neural network best reconstructed a reserved testing set of *in situ* SPM measurements with an R^2 value of 0.76. Although the Huber regression—an alternative to linear regression that is robust against outliers—did not predict SPM concentrations as well as the neural network ($R^2 = 0.74$), it is a recommended alternative, because it possesses the attractive quality of being a linear equation that is straightforward to understand without sacrificing a large amount of performance. Therefore, we have implemented the Huber regression on a series of satellite images and used it to estimate surface SPM concentrations throughout San Francisco Bay.

Keywords: suspended sediment, suspended particulate matter, remote sensing, satellite imagery
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Evaluation of the Effects of Long-Term Trends in Sediment Supply and Wind Speeds on Suspended Sediment and Turbidity in Suisun Bay and the Delta

Michael MacWilliams, Anchor QEA, mmacwilliams@anchorqea.com
Aaron Bever, Anchor QEA, abever@anchorqea.com
David Fullerton, Metropolitan Water District, dfullerton@mwdh2o.com

Observed long-term trends indicate a decline in sediment supply to the Delta on the order of 1.3% per year, which corresponds to a decline of 23% over the past 20 years. In addition, recent analysis of historic wind data in Suisun Bay and the Sacramento-San Joaquin Delta indicates a statistically significant decline in wind speeds over the past two decades, which is most pronounced in fall. Both the long-term decline in sediment supply and the long-term trends in wind speed have the potential to influence sediment transport and turbidity in Suisun Bay and the Delta. The 3-D UnTRIM Bay-Delta model was applied together with the SWAN wave model and the SediMorph morphodynamic model to evaluate the relative effect of long term trends in wind and Delta sediment supply on turbidity both during wet and dry water years. An understanding of how these long term trends in wind and Delta sediment supply affect turbidity in Suisun Bay and the Western Delta has important management implications for species such as Delta Smelt that are more likely to be detected in areas with higher turbidity. This presentation will discuss the observed declines in sediment supply and wind speed, how these declines have affected turbidity over the past 20 years, and the potential implications of these changes for habitat and management decisions.

Keywords: Sediment Transport, Wind, Turbidity, Waves, Sediment Supply, Delta Smelt Habitat
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Observations of Cohesive Sediment Flocculation in San Francisco Bay: Implications on Sediment Transport and Light Availability

Ivy B. Huang*, Stanford University, ibhuang@stanford.edu
Andrew J. Manning, Coasts & Estuaries Group, HR Wallingford Ltd.; and Department of Geography, Environment & Earth Sciences, University of Hull, a.manning@hrwallingford.com
David H. Schoellhamer, USGS California Water Science Center, dschoell@usgs.gov
Stephen G. Monismith, Stanford University, monismith@stanford.edu

This research is focused on determining cohesive sediment properties in San Francisco Bay, identifying the controls on flocculation dynamics, and investigating the effects of particle size changes on sediment residence time and light penetration. High-resolution transect and stationary measurements of flow, turbulence, turbidity, sediment concentration, particle size, and light penetration were collected between 2008 and 2015, spanning from South Bay to Sacramento. We make the following main observations. First, suspended sediment flocculation significantly enhances particle fall velocity and, therefore, sediment removal from the water column. Second, we argue that estuarine physics is the main driving mechanism behind floc size changes, rather than chemical or biological factors. Lastly, we show that suspended sediment and light penetration relationships can be improved by accounting for floc size changes under certain conditions. Overall, conclusions drawn from this research will aid in the evaluation of pressing environmental problems in the Bay-Delta estuary that are intimately linked to sediment and light relationships.

Keywords: Cohesive sediment, turbulence, flocculation, turbidity, light penetration
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Three-dimensional Modeling of Turbidity in the Sacramento-San Joaquin Delta to Investigate the Mechanisms Resulting in Tidal Time-scale Lateral Turbidity Gradients

Aaron Bever, Anchor QEA, abever@anchorqea.com
Michael MacWilliams, Anchor QEA, mmacwilliams@anchorqea.com

The 3-D UnTRIM Bay-Delta hydrodynamic and sediment transport model was used to predict the suspended sediment concentration throughout the Sacramento-San Joaquin Delta. The 3-D suspended sediment concentration was converted to turbidity and the turbidity then underwent data assimilation using observations from turbidity monitoring sensors. This method preserved both the Delta-scale and the small-scale lateral and vertical turbidity gradients predicted by the 3D model while also ensuring the simulated turbidity field matches the locally observed turbidity magnitude throughout the Delta. The model results were examined taking into account a simple conceptual model proposed by Bennett and Burau (2015) of across-channel turbidity gradients, to determine the mechanisms influencing lateral turbidity gradients in the Sacramento River near the junction with Three Mile Slough. The high-resolution predicted turbidity highlights the large influence of channel junctions on lateral turbidity gradients near Three Mile Slough and throughout the Delta. Tidal time-scale variability in water flow and the resulting effects on sediment erosion, deposition, and transport is also shown to influence the formation and breakdown of lateral turbidity gradients.

Keywords: Turbidity, Numerical Modeling, Sediment, Lateral Turbidity Gradients
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Influence of the 2016 Yolo Bypass Flood Event on Suspended Sediment in Little Holland Tract

Emily Carlson, USGS, emilycarlson@usgs.gov
Jessica Lacy, USGS, jlacy@usgs.gov

Delta smelt favor regions of elevated turbidity, and in much of the Delta turbidities are low. During the fall of 2015 and the winter of 2016 a suite of instruments were deployed in Liberty Island and Little Holland Tract (LHT) in the northern Sacramento Delta as part of a collaborative effort to characterize the suitability of Little Holland Tract as fish habitat. Persistent rain events in February and March of 2016 resulted in the overtopping of the Fremont Weir for the first time in three years, diverting flow from the Sacramento River into the Yolo Bypass from March 12th until March 24th. LHT is located approximately 32 miles south (downstream) of the weir, near where the bypass reconnects to the main Sacramento River channel. During the flood event, water levels were elevated in LHT, and both tidal stage fluctuations and tidal currents were significantly damped, increasing the potential for sediment deposition. The greatest suspended-sediment concentration (SSC) in the study area since observations began in August 2015 occurred directly before and during the Yolo Bypass flood. After the flood event, SSC in LHT remained higher than before the period of highest SSC, suggesting that erodibility increased. Bed sediment samples collected at two sites before and after the flood event show an increase in fines and a decrease in larger particle size. The apparent change in erodability and particle size distribution indicate that there was an influx of new sediments into LHT from the flood bypass area. In contrast, the westerly adjacent water body, Liberty Island, experienced similar elevations in water levels but did not exhibit comparable changes in SSC and grain size distribution. These results illustrate the importance of location relative to sediment sources in selecting restoration sites.

Keywords: sediment transport, sediment dynamics, Yolo Bypass, turbidity, management decisions
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Mudflat Morphodynamics and the Impact of Sea Level Rise in South San Francisco Bay

Mick van der Wegen, UNESCO-IHE and Deltares, m.vanderwegen@unesco-ihe.org
Bruce Jaffe, USGS, bjaffe@usgs.gov
Amy Foxgrover, USGS, afoxgrover@usgs.gov
Dano Roelvink, UNESCO-IHE, Deltares and TU Delft, d.roelvink@unesco-ihe.org

Estuarine tidal mudflats form unique habitats and maintain valuable ecosystems. They provide an important source of sediment to adjacent salt marshes. In addition, wave attenuating by the salt marsh-mudflat system provides a natural defense against wave attack during storms. Although many mudflats seem to be in equilibrium, it is unknown how mudflats will react to scenarios of sea level rise and decreasing sediment supply.

We developed a 1D morphodynamic profile model (Delft3D) that is able to reproduce the 2011 measured profile at a 800 wide mudflat south of Dumbarton Bridge. The physics-based model included tide and wave action as well as the Krone-Parteniades sediment transport formulation. The modeling approach allows for a detailed analysis of governing processes during the tidal cycle at a 10 m spatial resolution as well as morphodynamic developments over a 100 year time frame.

The model is able to reproduce the measured Dumbarton mudflat profile in equilibrium conditions including high, wave induced, suspended sediment concentrations at the mudflat. Shear stresses are highest during low water, while shear stresses are lower than critical (and highest at the landward end) along the mudflat during high water. Scenarios of sea level rise and decreasing sediment supply drown the mudflat and reduce intertidal area. For example, a 1.67m rise in sea level in a century reduces the intertidal area by about 30 percent. This is despite the fact that the mudflat profile accretes on average 1 m.

This research suggests that sea level rise is a serious threat to the presence of many estuarine intertidal mudflats, adjacent salt marshes and their associated ecological values.

Keywords: estuarine mudflats, morphodynamic modeling, sea level rise impact
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Morphologic Change and Mercury Mobilization in Alviso Slough, South San Francisco Bay

Amy Foxgrover, USGS Pacific Coastal and Marine Science Center, afoxgrover@usgs.gov
Theresa Fregoso, USGS Pacific Coastal and Marine Science Center, tfregoso@usgs.gov
Bruce Jaffe, USGS Pacific Coastal and Marine Science Center, bjaffe@usgs.gov
Mark Marvin-DiPasquale, USGS, Branch of Regional Research, Western Region, mmarvin@usgs.gov

The potential for localized and regional erosion of intertidal mudflats, sloughs, and channels is a major concern associated with salt pond restoration in South San Francisco Bay. Two of the primary uncertainties in restoration of the Alviso Salt Ponds are: (1) Will opening these severely subsided ponds to tidal action result in erosion of the adjacent mudflats? (2) Will the enlarged tidal prism significantly increase the rate of scour within Alviso Slough and remobilize legacy mercury deposits that were previously buried? Restoration began in 2010 when the levees surrounding Pond A6 were breached, and muted tidal action was restored to the Pond A8 complex through an adjustable flood control structure, allowing for progressively increased size and duration of tidal flushing. As part of the adaptive management process, we collected a baseline high-resolution bathymetric survey of the study area during 2010, followed by semi-annual surveys ever since. Thus far, the greatest amount of erosion has occurred within Alviso and Guadalupe Sloughs in the vicinity of the A6 breaches. From 2010 to 2015 the nearby intertidal mudflats have either accreted or maintained their elevation. Patterns of deposition and erosion vary along the length of Alviso Slough and through time. There has been a dominant pattern of erosion in the winter followed by either no change or slight deposition with only localized areas of erosion during spring and summer months. Our measurements of scour within Alviso Slough, in combination with mercury data from deep (ca. 2 meter) sediment cores indicate that approximately 35 kg of legacy mercury has been remobilized within the slough between 2010 and October 2015. This study provides critical insight into the morphological evolution of slough/intertidal mudflat/bay systems as levees are breached and the tidal prism increased, while informing future wetland management and restoration practices.

Keywords: South San Francisco Bay, restoration, Alivso, salt ponds, mercury, bathymetry
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Seasonal Variations in Suspended Sediment in San Pablo Bay Shallows

Rachel Allen*, University of California, Berkeley, rachelallen@berkeley.edu
Evan Variano, University of California, Berkeley, variano@berkeley.edu
Jessica Lacy, USGS Pacific Coastal and Marine Science Center, jlacy@usgs.gov

Models of marsh response to sea-level rise require sediment supply as a key input, and it is currently parameterized with high uncertainty. This work aims to improve the mechanistic understanding of suspended sediment dynamics with long-term measurements in San Pablo Bay.

San Pablo Bay is the site of an extensive historic marsh and several large-scale marsh restoration projects. The sediment supply to these marshes depends on conditions in adjacent bay shallows. It is known that currents, waves, water level, and their interactions drive suspended sediment conditions in San Francisco Bay shallows. However, the importance of longer term forcings on a seasonal scale, such as winter storms, event-driven freshwater inflows, sustained winds, variations in wind direction, and long-term low-energy periods, have not previously been investigated. We observed suspended sediment concentrations and wave, current, and turbulence conditions in San Pablo Bay over 16 months, between Dec 2013 and April 2015. We collected data every 15-20 min at two stations about 7 km apart along the western shore, both located at 1 m below mean-lower-low water.

Suspended sediment concentrations were generally lower at the southerly station, which is protected from the prevailing winds. The highest concentrations were observed during the 2014-2015 winter, while the drier 2013-2014 winter showed similar behavior to the rest of the 2014 spring-summer-fall. To investigate these differences and the seasonal variation of suspended sediment dynamics, we explore resuspension and critical shear stress, spatial variation within the shallows and between the shallows and the marsh, and the relationship of seasonal-scale drivers to currents, waves, winds, and tides.

This study improves our mechanistic understanding of suspended sediment dynamics, and enables us to make better predictions of marsh survival with sea level rise and better management decisions about marsh restoration around San Francisco Bay.

Keywords: suspended sediment dynamics, seasonal trends
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Linking Sediment Flux to Marshes with Dynamics in Bay Shallows

Jessica Lacy, USGS Pacific Coastal and Marine Science Center, jlacy@usgs.gov
Rachel Allen, UC Berkeley, rachelallen@berkeley.edu
Madeline Foster-Martinez, UC Berkeley, madeline@berkeley.edu
John Callaway, University of San Francisco, callaway@usfca.edu
Matthew Ferner, San Francisco Bay National Estuarine Research Reserve, mferner@sfsu.edu

Predictions of marsh resilience to sea-level rise rely on estimates of sediment supply, yet the links between dynamics in estuarine shallows and sediment supply to marshes are poorly understood. We are investigating these connections in the San Pablo Bay shallows and the adjacent accretionary marsh in China Camp State Park. Data collected in winter 2013/14 and winter 2014/15 show net sediment export from the marsh through tidal creeks, predominately during the largest ('King') tides of the year. During four days of King tides, 10 tons of sediment per meter of creek width were exported during the first winter, and 15 tons/m during the second winter. Ebbing tides after extreme high waters are delayed over the marsh surface by vegetative drag, increasing the along-creek gradient in water surface elevation. As a result velocities are elevated (> 1 m/s) in the creeks, suggesting that channel scour, rather than erosion of the marsh, accounts for much of the bayward suspended-sediment flux (SSF). Tidal creek SSF was landward (with low magnitude) during neap tides and wind events. From May to June 2016 we conducted a third deployment to capture the influence of the summer sea breeze and the highest tides of summer on SSF. Our data show that the highest suspended-sediment concentrations (SSC) occur over the intertidal mudflat adjacent to the marsh edge, due to wind-wave resuspension. During flood tides when the mudflat was inundated, the 85th percentile of near-bed SSC over the mudflat was 263 mg/L, compared to 191 mg/L in the subtidal shallows, and 56 mg/L over the vegetated marsh. Flood-tide SSC over the mudflat and in the tidal creek were highly correlated. These results indicate the importance of the dynamic region immediately bayward of the marsh edge to sediment supply, both through marsh creeks and directly across the bay-marsh interface.

Keywords: suspended sediment; sediment flux; tidal marsh; wind waves
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Wetland Sedimentation in Natural and Restored Tidal Wetlands in San Francisco Bay

John Callaway, University of San Francisco, callaway@usfca.edu

There is large-scale interest in restoring tidal wetlands within the Bay-Delta; however, many restoration sites are highly subsided and will require substantial sediment accumulation to reach threshold elevations for plant establishment. In addition to these issues, there is growing concern regarding impacts from increased rates of sea-level rise and reductions in suspended sediment concentrations within the Bay-Delta. Given these concerns, it is critical to better understand wetland sediment dynamics within both restored and natural wetlands in the Bay-Delta. To address this issue, we have measured sedimentation rates in a range of sites using both long-term and short-term approaches, including dated sediment cores, feldspar marker horizons and SETs. Sampling has occurred at multiple natural and restored wetlands, and across a wide range of intertidal elevations, from unvegetated mudflats to high-elevation marsh plains. Results indicate that existing tidal wetlands throughout San Francisco Bay and Suisun Bay are keeping pace with current rates of sea-level rise, with overall accretion rates ranging from 2-4 mm/yr in high-elevation marsh plains to 6-8 mm/yr in low marsh areas. Recently restored sites have substantially higher rates of accretion (up to 200 mm/yr), due to more frequent tidal inundation at lower elevations within subsided restoration sites. It is not certain if these extreme rates of accretion are likely to continue as more sites are restored within the Bay-Delta and if suspended sediment continues to decline into the future; however, at present, conditions indicate that restoration sites have the potential to increase elevation rapidly. Continued monitoring of additional wetlands within the Bay-Delta will allow for the development of models which can be used to predict sediment dynamics in future restoration projects, as well to understand longer-term development of restored wetlands under scenarios of increased sea-level rise and reduced suspended sediment concentrations.

Keywords: accretion, restoration; sea-level rise, sedimentation, wetland
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