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ANCHOR QEA

Regional Monitoring Program Special Study Proposal
Golden Gate Sediment Flux Modeling

May 9, 2018

To: Philip Trowbridge, PE, Program Manager, Regional Monitoring Program for Water Quality in San Francisco Bay

From: Michael L. MacWilliams, PhD, PE, Anchor QEA, LLC

Re: Golden Gate Sediment Flux Modeling

Proposal Summary	The U.S. Geological Survey (USGS) measured sediment fluxes through the Golden Gate during complete tidal cycles in March and June 2016 and February 2017. The sediment flux measurements in February 2017 showed a greater sediment flux into San Francisco Bay on flood tide than the flux out on the preceding ebb tide. USGS hypothesized that this result occurred because the measurements were made on the falling limb of the hydrograph and that during peak outflows the sediment flux out was greater than the flux in. This study proposes to simulate the sediment flux across the February 2017 high flow period, validate the model-predicted sediment flux using the one tidal cycle of flux observations collected by USGS, and then compute the total predicted sediment flux through the Golden Gate over a 3-month period. The primary motivation is to understand why the measured sediment flux back into the Bay during the observation period was greater than the flux out, and whether this is related to being on the tail end of the sediment pulse. The model simulations can also be used to assist in developing surrogate measurements of sediment flux at the Golden Gate that are critical for understanding the overall sediment mass balance in San Francisco Bay. The predicted sediment flux at the Golden Gate will be compared to observed parameters such as suspended sediment concentration (SSC) at Alcatraz or Sacramento-San Joaquin Delta (Delta) outflow to develop these relationships. Predicted sediment fluxes between each subembayment will also be calculated from this simulation to inform calculation of sediment fluxes within the Bay.
Relevant Management Questions	**MQ3:** What are the sources, sinks, pathways, and loadings of sediment and sediment-bound contaminants to and within the Bay and subembayments? **MQ5:** What are the concentrations of suspended sediment in the Estuary and its segments? One of the single greatest uncertainties related to developing a sediment budget for San Francisco Bay is the uncertainty related to the sediment flux at the Golden Gate. The application of an existing hydrodynamic and sediment transport model to simulate the period of data collection will add value to the existing data set from February 2017 by helping to understand sediment fluxes immediately prior to the sampling event during peak flows and allow for an assessment of why the measured flux back into the Bay during the observation period was greater than flux out (MQ3). The model predictions will also be compared to observed SSC throughout the Bay (MQ5).
Estimated Cost	$45,000
Proposed by	Michael L. MacWilliams, PhD, PE, and Aaron Bever, PhD, Anchor QEA, LLC

1. Background

This project will apply an existing 3-D hydrodynamic, salinity, and sediment transport model of San Francisco Bay to predict sediment fluxes at the Golden Gate and between each subembayment of the Estuary. This project leverages an existing model that has already been extensively calibrated and validated for SSC throughout the Estuary and the Delta and will build on existing work currently being conducted to simulate sediment concentrations in Suisun Bay and the Delta during 2017. As a result, this project provides a cost-efficient way to add significant value to the data set collected by USGS in February 2017, provides a way to investigate the hypothesis that the net sediment flux into the Bay through the Golden Gate was positive because the measurements were made on the falling limb of the hydrograph and that during peak flows the flux out was greater than the flux in, and provides additional information that can be used to develop surrogate flux estimates.

While simulating the two periods in March and June 2016 when flux measurements were made would also provide additional information that would be useful in understanding sediment fluxes at the Golden Gate, this proposal only includes simulations of the first three months of 2017 to keep the cost down. Based on what we learn from the modeling of 2017 period, an additional simulation spanning March and June 2016 could be simulated using the same approach at a later date if additional funding is available.

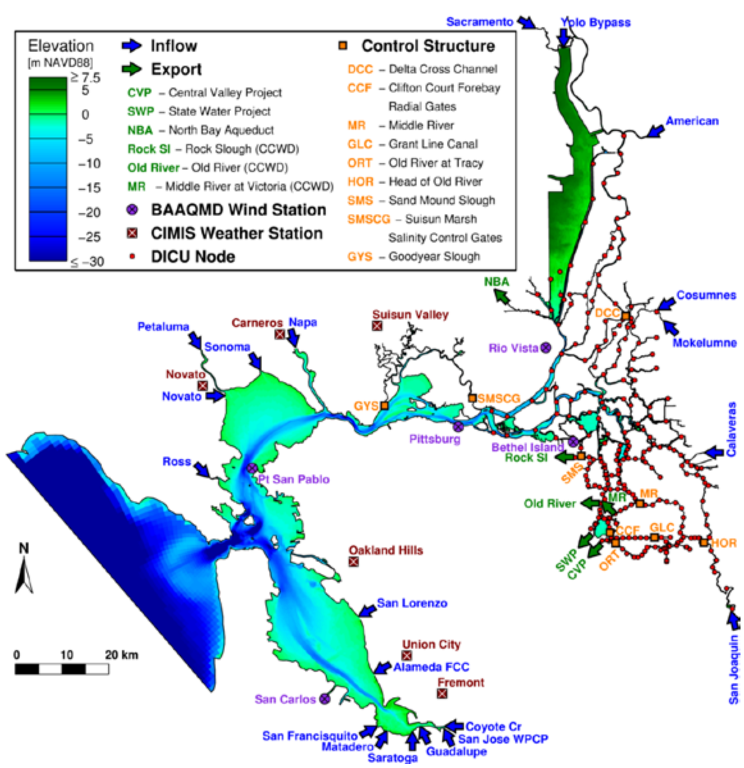
1.1 Sediment Modeling Background

The UnTRIM Bay-Delta model (MacWilliams et al. 2007, 2008, 2009, 2015) will be applied together with the SWAN (SWAN Team 2009a) wave model and the SediMorph sediment transport and seabed morphology model (BAW 2005), as a fully-coupled hydrodynamic-wave-sediment transport model. This coupled modeling system has been used previously to predict sediment transport throughout the Bay-Delta system, as part of two projects for the U.S. Army Corps of Engineers (USACE) to investigate how sea level rise and a reduced sediment supply to the Delta impacted the sediment routing through the Bay-Delta system and the sediment deposition within Suisun and San Pablo Bays (MacWilliams et al. 2012; Bever and MacWilliams 2014). The coupled models were also used to investigate the effects of breaching Prospect Island on regional turbidity and sediment dynamics in the north Delta and Cache Slough region (Delta Modeling Associates 2014). Other applications of the sediment transport model include simulations of dredged material dispersal in Northern San Francisco Bay (MacWilliams et al. 2012) and South San Francisco Bay (Bever and MacWilliams 2014; Bever et al. 2014) to determine the fate of dredged material and investigate whether open water placements can potentially be used to augment mudflat and marsh sedimentation. Bever and MacWilliams (2013) applied the coupled modeling system to investigate wave shoaling and sediment fluxes between the channel and shoals in San Pablo Bay. The model has also been used to investigate sediment fluxes at Dumbarton Bridge (Delta Modeling Associates 2013), following a similar approach to that proposed in this study.

The UnTRIM San Francisco Bay-Delta model (UnTRIM Bay-Delta model) is a 3-D hydrodynamic model of San Francisco Bay and the Delta developed using the UnTRIM hydrodynamic model (MacWilliams et al. 2007, 2008, 2009, 2015). The UnTRIM Bay-Delta model extends from the Pacific Ocean through the entire Sacramento-San Joaquin Delta (Figure 1), and takes advantage of the grid flexibility allowed in an unstructured mesh by gradually varying grid cell sizes, beginning with large grid cells in the Pacific Ocean and gradually transitioning to finer grid resolution in the smaller channels of the Delta. This approach offers significant advantages both in terms of numerical efficiency and accuracy and allows for local grid refinement for detailed analysis of local hydrodynamics, while still incorporating the overall hydrodynamics of the larger estuary in a single model.

The SWAN model (SWAN Team 2009a) is a widely used model for predicting wind wave properties in coastal areas (e.g., Funakoshi et al. 2008). SWAN "represents the effects of spatial propagation, refraction, shoaling, generation, dissipation and nonlinear wave-wave interactions" (SWAN Team 2009b) on wind waves. Therefore, SWAN can estimate the wind waves in coastal regions with variable bathymetry and ambient currents. SWAN can also accommodate spatial variability in bottom friction parameters and wind velocity. In the coupled modeling system, the SWAN model runs on the same unstructured grid as UnTRIM, providing high resolution in areas where it is needed.

Figure 1
Model domain and boundary conditions for the UnTRIM Bay-Delta model

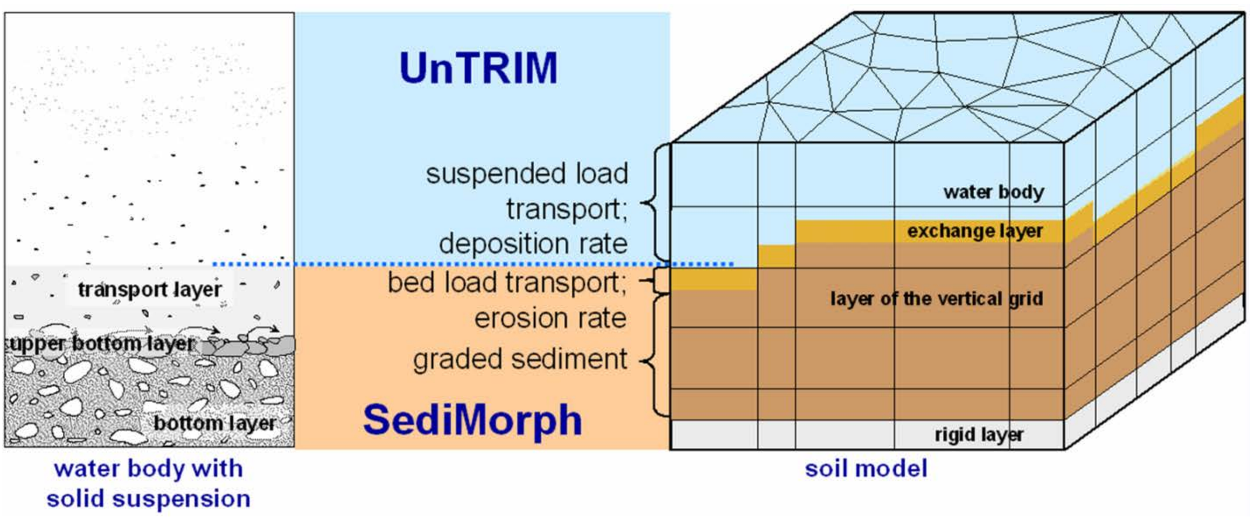


The primary purpose of the SediMorph module is to compute the sedimentological processes at the alluvial bed of a free-surface flow, including the following (Weilbeer 2005):

- The roughness of the bed resulting from grain and form roughness (ripples and/or dunes)
- The bottom shear stress as a result of roughness, flow, and waves
- Bed load transport rates (fractioned)
- Erosion and deposition rates (fractioned)
- Bed evolution
- Sediment distribution within the bed exchange layer

SediMorph is designed to use the same horizontal computational mesh as the UnTRIM hydrodynamic model. In the vertical, the SediMorph module allows for evolution of the bed elevation above a pre-defined rigid layer in each cell. Above the rigid layer, SediMorph includes at least one exchange layer in which sediments are mixed and exchange processes such as erosion and deposition occur. Figure 2 shows the horizontal and vertical grid structure of the UnTRIM and SediMorph models and provides a schematic representation of the location of the sediment transport processes within the model grid structures.

Figure 2
Horizontal and vertical grid structure of the UnTRIM and SediMorph models (right); schematic (left) and process list (middle) show the location of the sediment transport processes within the model grid structures (Source: BAW)



Sediment transport simulations using the UnTRIM San Francisco Bay-Delta Model include multiple sediment classes, an initial sediment bed based on over 1,300 observed seabed grain size distributions within the Bay and the Delta, sediment input from 10 Bay-Delta tributaries, and wave- and current-driven sediment resuspension and transport.

In this coupled modeling system, UnTRIM calculates the flow, water level, salinity, sediment advection, sediment settling, and sediment mixing. SWAN calculates the temporally and spatially varying waves needed for accurate predictions of sediment resuspension in the presence of wind waves. SediMorph calculates the erosion and deposition of sediment and the seabed morphologic change, and keeps track of the sedimentological properties within the seabed. The model bathymetry in each grid cell is adjusted each time step to account for erosion and deposition.

The calibration and validation of salinity, flow, and water level in the UnTRIM Bay-Delta model has been well-documented (e.g., MacWilliams et al. 2007, 2008, 2009, 2015). The model accurately predicts the salinity, flow, and water level throughout the San Francisco Bay and the Delta under a wide range of conditions. The SWAN wave results have been calibrated and validated to observed wave properties in San Pablo and Suisun Bays and at four locations south of Dumbarton Bridge. The sediment transport within the coupled modeling system has been calibrated using SSC time series at five stations within San Francisco Bay (red squares on Figure 3), eight stations within the Sacramento-San Joaquin Delta (orange triangles on Figure 3), and using vertical SSC profiles along a transect along the axis of San Francisco Bay from the far South Bay to Rio Vista (yellow circles on Figure 3). Figure 4 shows an example of the observed and predicted SSC at Rio Vista spanning a 7-month period during water year 2011. This shows that the model accurately predicts both the magnitude and seasonal patterns of SSC in the Sacramento River indicating the model is accurately predicting the outflow of sediment from the Delta during high flows. Figure 5 shows a comparison of observed and predicted SSC along the axis of San Francisco Bay on June 14, 2011, and demonstrates that the model is capturing the primary features in the vertical and longitudinal SSC. The model has also been validated through comparison of observed and predicted deposition within a breached salt pond during the period following the initial breach (Bever and MacWilliams 2014). The sediment validations demonstrate that the coupled hydrodynamic-wind wave-sediment model is accurately capturing the processes that resuspend, deposit, and advect sediment throughout the Bay-Delta system, and would therefore be suitable for evaluating sediment fluxes both at the Golden Gate and between each subembayment of the Bay. By simulating suspended sediment processes directly, the physical feedbacks between changing forcing and their influence on local and regional sediment dynamics can all be explicitly evaluated.

Figure 3
The locations of SSC data within the San Francisco Bay (red squares), within the Delta (orange triangles), and for the transect vertical profiles (yellow circles)

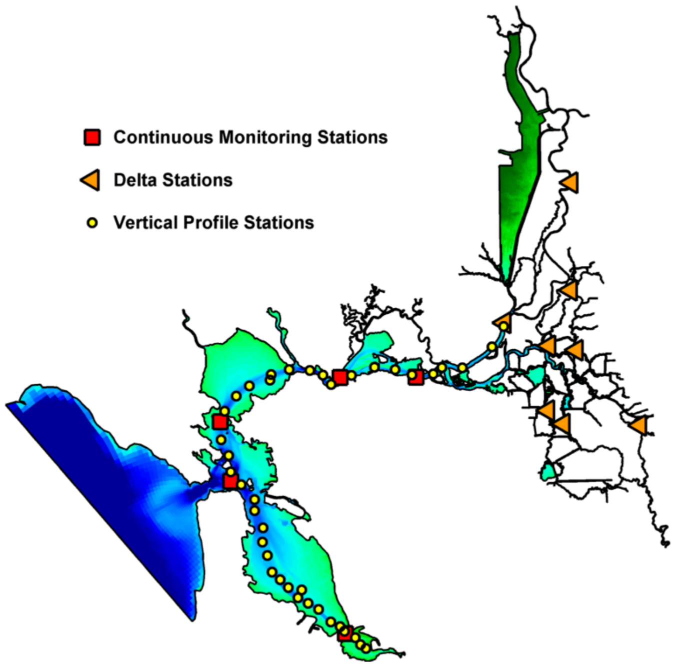


Figure 4
Observed and predicted cross-section average SSC at the Sacramento River at Rio Vista (RIO)

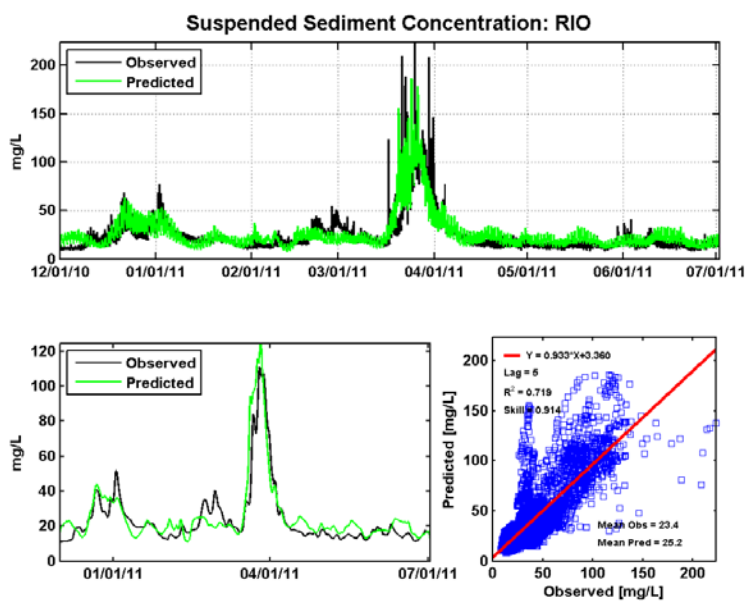
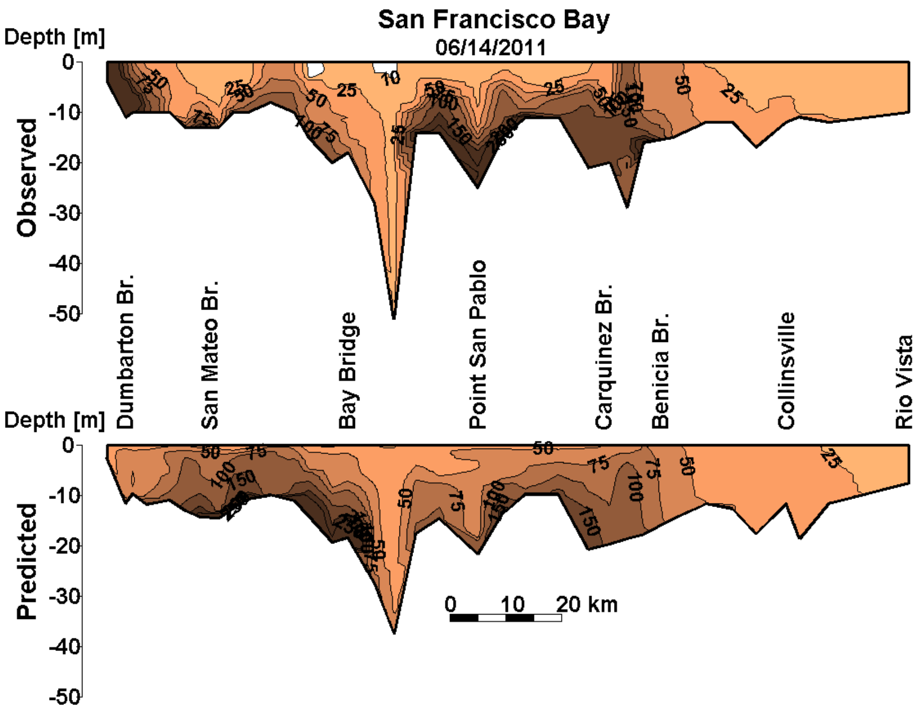


Figure 5
Observed and predicted SSC along a transect from the far South Bay to Rio Vista on June 14, 2011



1.2 Sediment Flux at Dumbarton Bridge

The UnTRIM Bay-Delta model was previously used to provide a detailed evaluation of sediment flux at Dumbarton Bridge based on data estimates and model predictions (Delta Modeling Associates 2013). Model results of water flow and sediment flux at Dumbarton Bridge were compared to USGS estimates. While the modeled and observed water flow agreed well on a tidal time scale, the directions of net observed and predicted water flow were different (Figure 6). The model predicted a net water flow toward the north out of the far South Bay (8.99 cubic meters per second [m^3/s]), while the USGS estimates have a southward net water flow (-46.9 m^3/s). When the model-predicted net flows in the channel (red line) are compared to the observed flows (black line), they match closely and indicate a net flow into the far South Bay (Figure 7). The boat-based sampling spanned only the channel and did not include the shoals (Figure 8). This analysis suggests that the discrepancy in the water net flow direction occurred because the observed flow does not include the northward net flow which occurs on the relatively shallow shoals, and that when the flows on the shoals are included, the net water flow is north (Figure 7, green line).

Figure 6
USGS estimated (Observed) and model predicted (Predicted) water discharge past Dumbarton Bridge from December 2010 through July 2011. The upper panel shows the instantaneous values while the lower left panel shows the tidal average. Negative discharge is southward into the far South Bay.

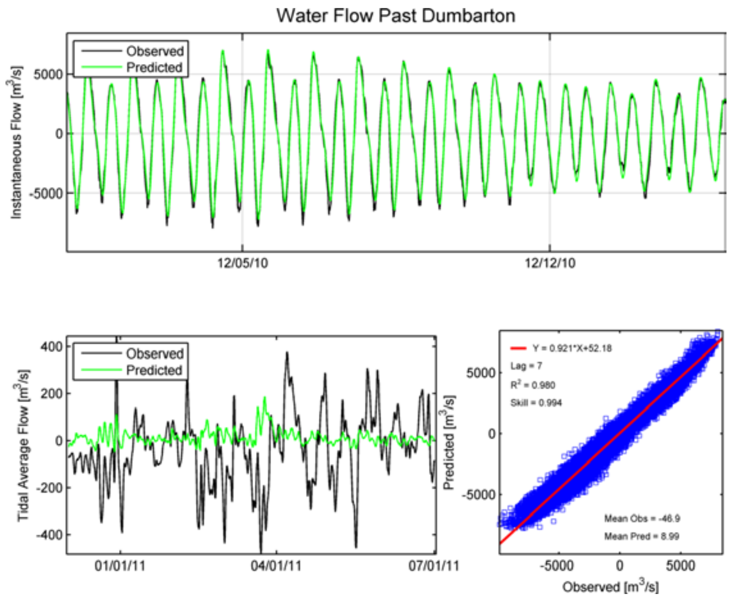


Figure 7
USGS estimated (Observed) and model predicted cumulative water discharge within the entire cross section (green) and in just the channel (red) past Dumbarton Bridge for December 2010 through July 2011. Negative flow is southward into the far South Bay.

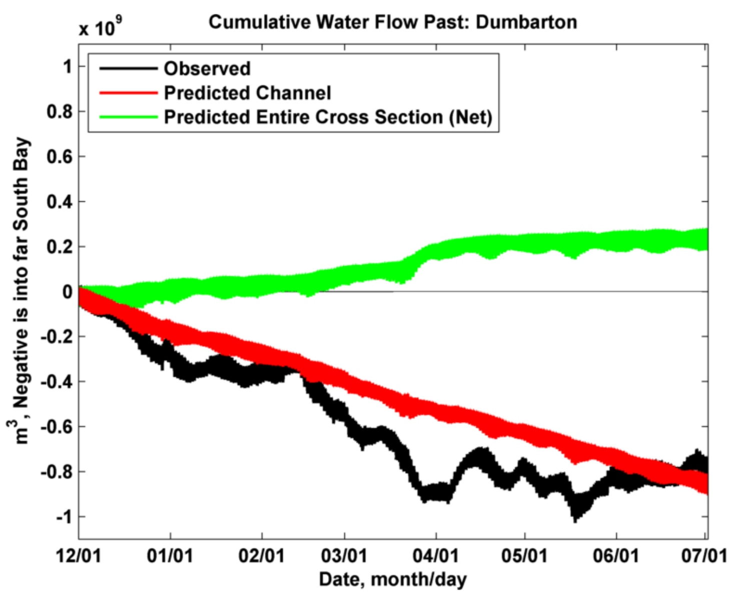
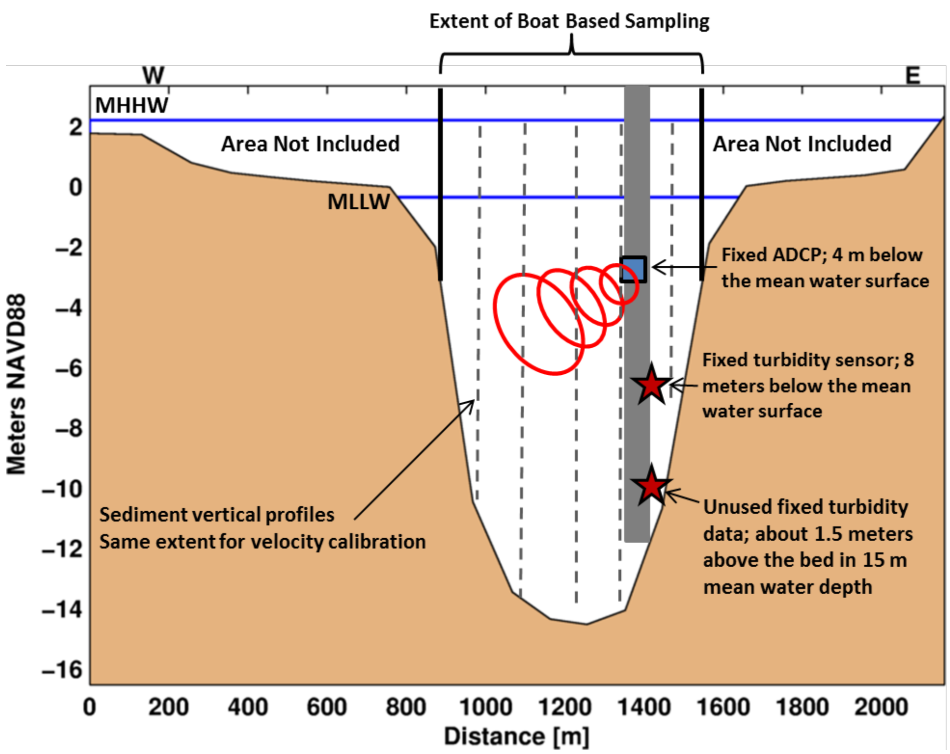
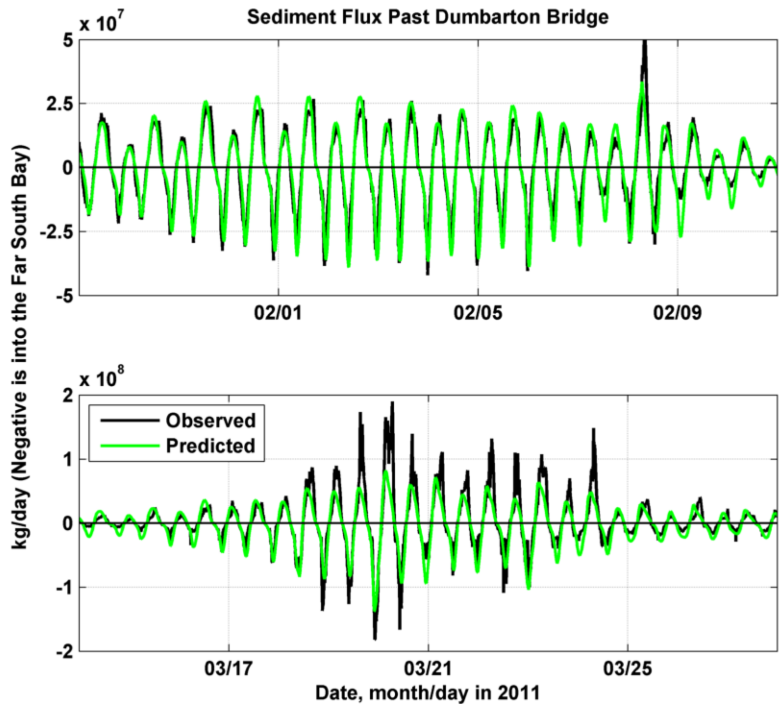


Figure 8
The cross section underneath Dumbarton Bridge highlighting the deeper main channel and shallower shoals. The water surface shows the mean higher high water (MHHW) and mean lower low water (MLLW) levels at Dumbarton Bridge. The thick grey line represents the bridge piling with the ADCP (blue square) and turbidity (red stars) sensors (vertical and horizontal locations are approximate). The dashed grey lines show the approximate locations of the vertical profiles used to correlate the point SSC to cross-section averaged concentration. The approximate extent of the boat-based sampling for determining the cross-section quantities is also shown.



The modeled and observed sediment fluxes also agreed well on a tidal time scale (Figure 9), yet had different net flux directions, with the net flux from the model toward the south and from the USGS estimates toward the north. A detailed comparison of multiple sediment flux estimates calculated using the available SSC data suggested that the USGS estimated sediment flux may overestimate the northward sediment flux (Delta Modeling Associates 2013). The analysis suggested that this northward overestimate may occur because only the SSC from the upper turbidity sensor on Dumbarton Bridge was used to determine the cross-sectional SSC. Sediment flux estimates calculated using the upper sensor result in a much more northward sediment flux compared to calculating the flux using the lower sensor or the average of the two sensors. The model results demonstrated that the sediment concentration near the bed was not in phase with the sediment concentration higher in the water column (which was also confirmed using the data), and thus the observed sediment flux direction was highly sensitive to which sensor was used to calculate the flux. Because of this analysis, USGS conducted additional data collection to improve the estimate of sediment flux at Dumbarton Bridge. This demonstrates the utility of applying a 3-D hydrodynamic and sediment transport model to understand and investigate the data used to estimate observed sediment fluxes.

Figure 9
Observed and predicted instantaneous sediment flux past Dumbarton Bridge for two time periods. These time periods are shaded in Figure 6 for reference.



1.3 Sediment Flux at the Golden Gate

USGS measured sediment fluxes through the Golden Gate during complete tidal cycles in March and June 2016 and February 2017. Observed sediment fluxes are calculated by multiplying the measured discharge across the cross-section by the sediment concentration across the section (Figure 10). Discrete measurements of sediment concentrations were estimated from backscatter and velocity transects were measured using a boat-mounted ADCP for approximately 32 transects on February 27, 2017 (Figure 11). However, the sediment flux measurements in February 2017 showed a greater sediment flux into San Francisco Bay on flood tide than the flux out on the preceding ebb tide (Figure 12). USGS hypothesized that this result occurred because the measurements were made on the falling limb of the hydrograph and that during peak flows the flux out was greater than the flux in. The model will be used to investigate this hypothesis. Previous comparisons of model simulations of sediment flux at Dumbarton Bridge (Delta Modeling Associates 2013) have demonstrated the utility of this approach, and ultimately resulted in improved sediment flux estimates from the observations.

Figure 10
Calculation of observed sediment flux from measurements (Source: USGS)

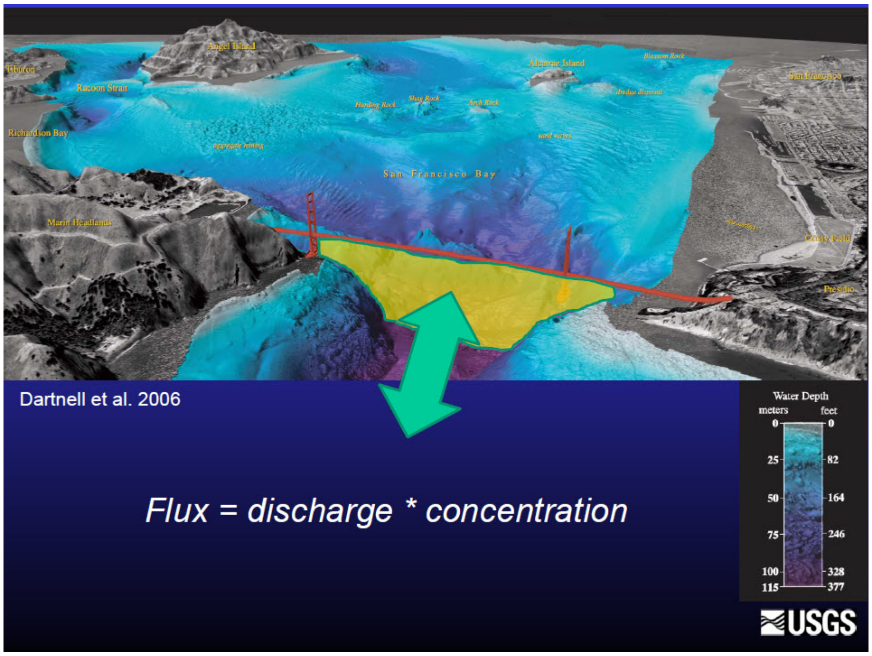


Figure 11
Example of measured acoustic backscatter (top) and velocity magnitude used to calculate observed sediment flux from measurements (Source: USGS)

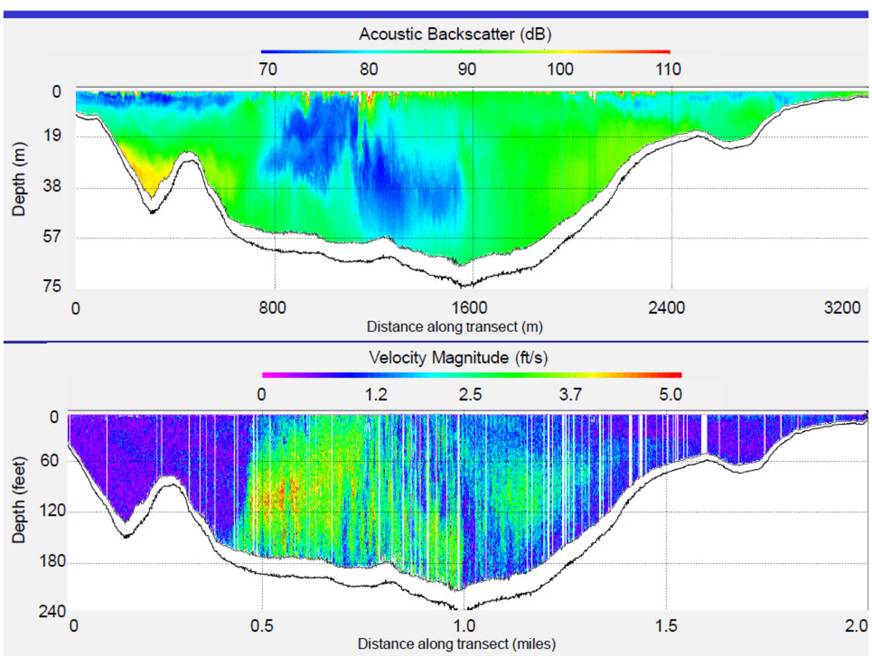
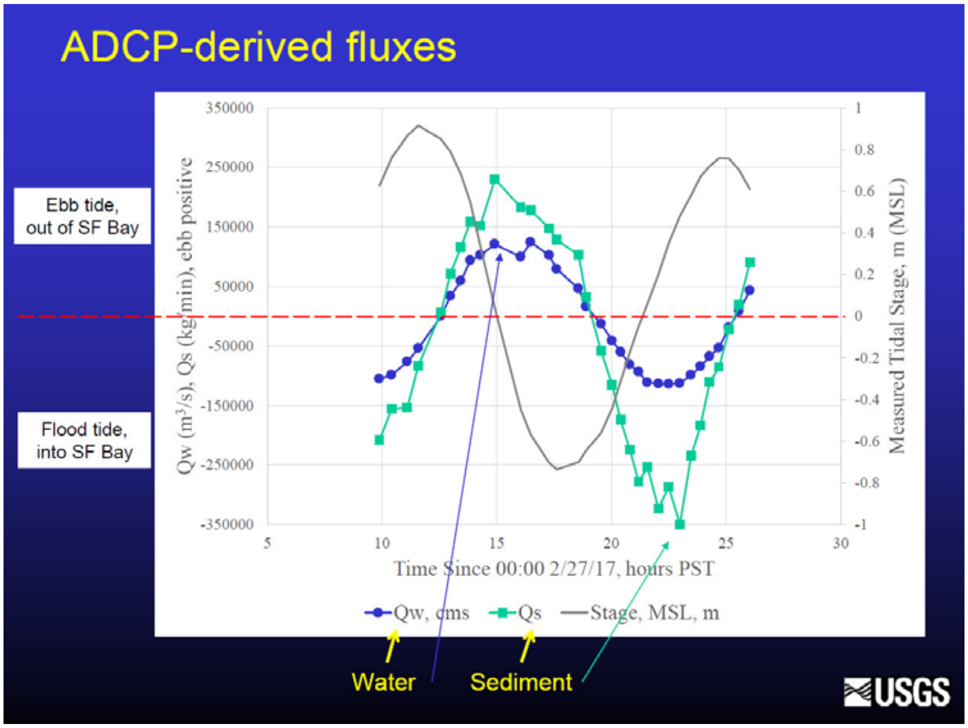


Figure 12
ADCP derived fluxes (water and sediment) at the Golden Gate on February 27, 2017 (Source: USGS)



II. Study Approach

The following section provides a detailed description of the work to be completed. Revisions or refinements to the scope of work can be made if requested.

Task 1: Simulation of Sediment Flux during January through March 2017

The UnTRIM Bay-Delta model will be used to simulate hydrodynamics, salinity, and sediment transport for the period from January 1, 2017, through March 31, 2017. This period spans the USGS sediment flux measurements at the Golden Gate made on February 27, 2017. This period is also particularly interesting because it spans two large outflow periods (Figure 13, top) and a period when the observed SSC at the Richmond San Rafael Bridge is higher than at Benicia (Figure 13, bottom).

The predicted sediment concentrations will be compared to observed SSC throughout the Estuary to validate model predictions of SSC. The sediment flux at the Golden Gate and between each of the subembayments of the Estuary will be calculated over the 3-month period. While the USGS sediment flux measurements span only a single day, the prediction of sediment fluxes during the 3-month high flow period in 2017 will allow for an increased understanding of how sediment fluxes vary on the rising and falling limbs of large outflow events.

During the data collection period on February 27, 2017, the model predictions of velocity and sediment concentration will be compared to the observed measurements of velocity and estimates of sediment concentration from backscatter (Figure 11). Previous comparisons between observed and predicted velocity transects have demonstrated that the model can accurately predict the complex velocity patterns near the Golden Gate (Figure 14). The model-predicted net flow, SSC, and net flux will be compared to the observations at each of the approximately 32 transects collected on February 27. This will allow for a detailed assessment of how differences between the predictions and observations affect the flux estimates for each discrete measurement transect.

Following the approach used at Dumbarton Bridge (Figure 9), the model-predicted sediment flux on each flood and ebb tide will be calculated for each day during the simulation period. These predictions will be used to investigate the hypothesis that the net sediment flux into the Bay through the Golden Gate during the sampling period was positive because the measurements were made on the falling limb of the hydrograph and that during peak flows the sediment flux out was greater than the flux in.

Because the model predictions of sediment flux at the Golden Gate will span a much longer period that the single day of data collection, the model predictions of sediment flux also be used to assist in developing surrogate measurements of sediment flux at the Golden that are critical for understanding the overall sediment mass balance in San Francisco Bay. The predicted sediment flux at the Golden Gate will be compared to observed parameters such as SSC at Alcatraz or Delta outflow to help develop these relationships.

The results of these analyses will be included in a draft technical memorandum which will be provided to the Regional Monitoring Program sediment workgroup for review. Based on the comments received, the document will be revised, and a final memorandum will be submitted.

Task 1 Deliverables

- Draft technical memorandum describing sediment simulation period, model validation to continuous monitoring sensors, model comparisons to observed sediment flux on February 27, and model predictions of sediment fluxes between embayments during simulation period
- Final technical memorandum incorporating revisions based on comments from the Regional Monitoring Program sediment workgroup

Figure 13
Observed flow, salinity, and SSC during 2017 (Source: USGS)

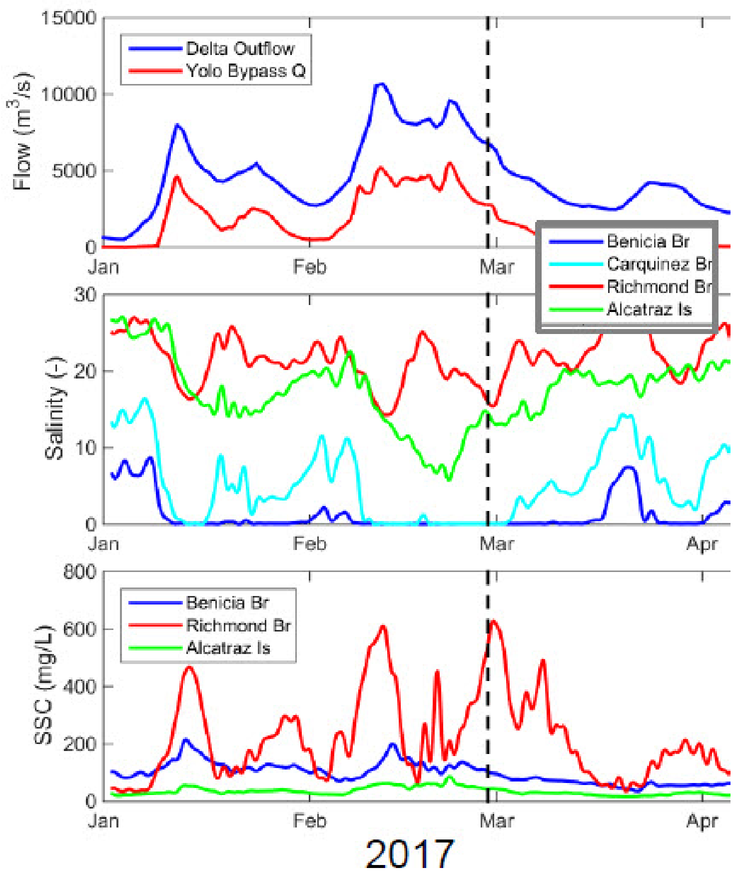
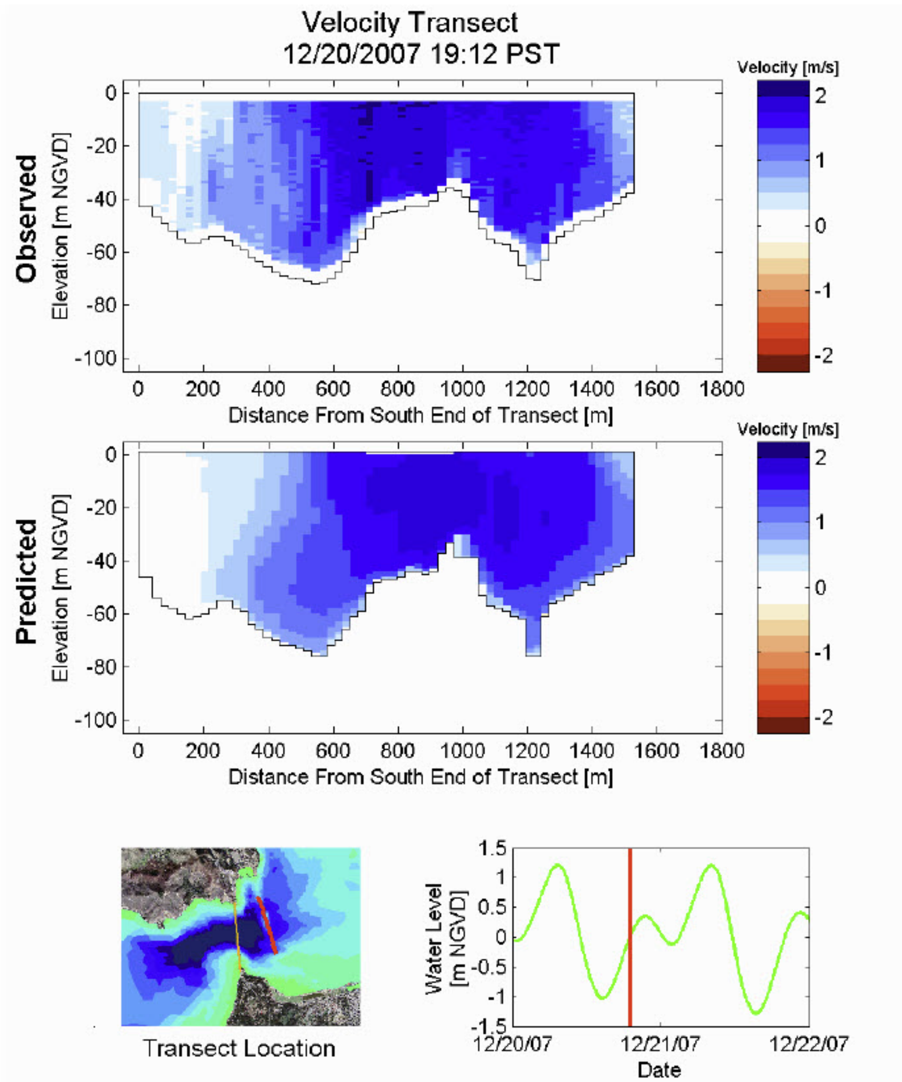


Figure 14
Observed (top) and predicted (middle) velocity transect on December 20, 2007, at 19:12 PST. The location of the transect (red line) is shown (lower left) relative to the position of the Golden Gate Bridge (orange line). Observed water level at Fort Point is shown with the red line indicating the start time of the transect (lower right).



4. Cost Estimate

A detailed project budget will be added after this scope of work is finalized. Based on the scope of work as described in the preceding sections, the estimated cost of this work is summarized in Table 1.

Table 1
Cost Estimate

Task Number	Description	Estimated Budget
1	Simulation of Sediment Flux from January through March 2017	$45,000
	Total	**$45,000**

5. Schedule

We anticipate that the draft technical memorandum will be completed within 4 months of notice to proceed. The final technical memorandum will be submitted within 1 month of receiving comments on the draft technical memorandum.

6. References

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