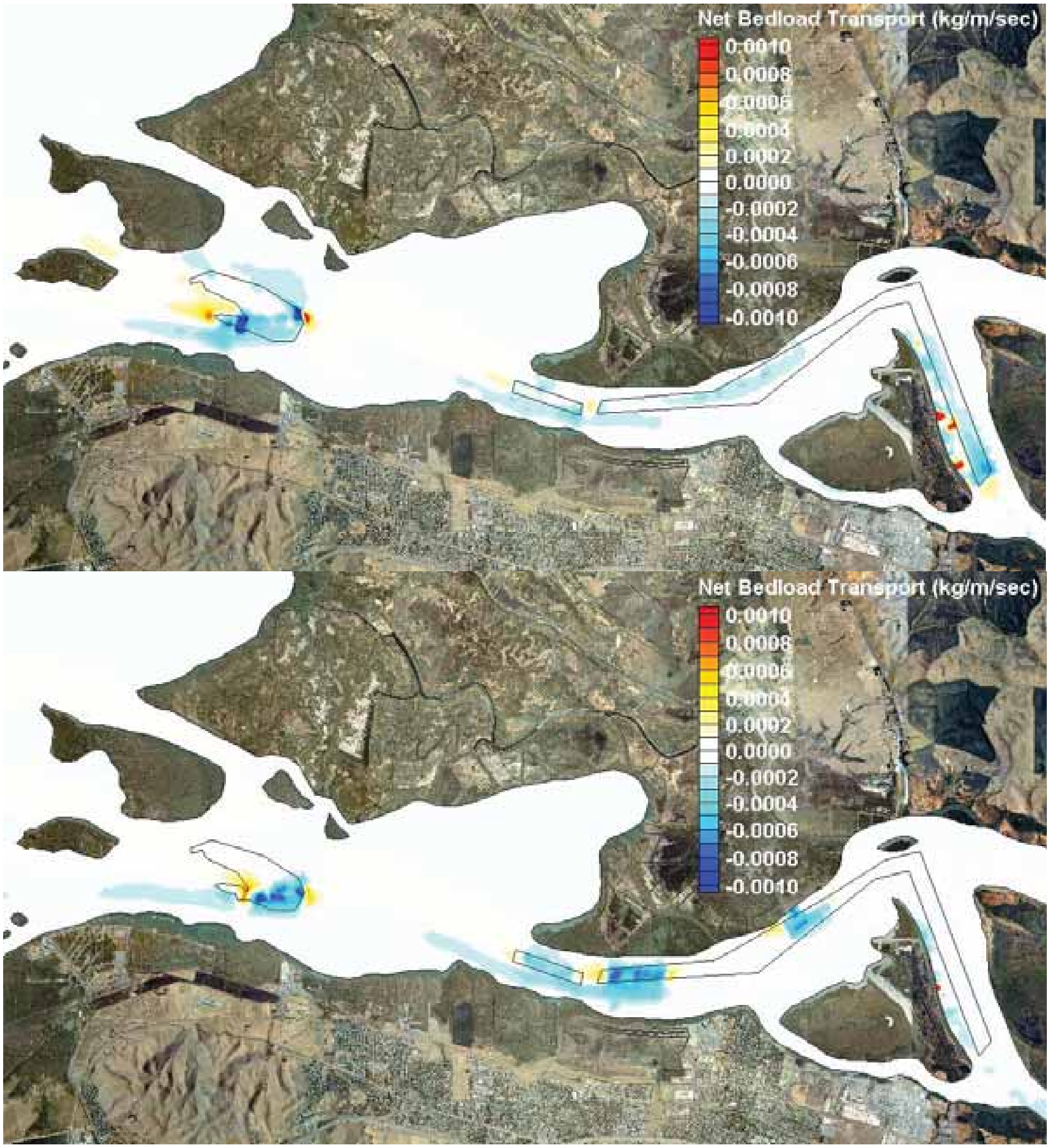

Figure 4-36. Scenario 1 (top) and Scenario 2 (bottom) changes in net bedload transport in Suisun Bay

4.2.7. Changes to Bottom Morphology due to Sand Mining

The LAGRSED model was used to predict bed changes occurring after the full one-year transport simulation using hydrologic/tide data from December 1996 to December 1997 and 2008 bathymetry conditions. Quantitative bed changes from the existing conditions simulation were not used in the analysis because hydrologic and tide data from the 1990s were used in combination with 2008 bathymetry, and many assumptions were required in development of the bottom sand distribution. It should be noted that no effort has been made to match observed bed changes with the predicted bed changes.

Figure 4-37 shows the predicted one-year sand bed changes for Central Bay (top) and Suisun Bay (bottom) for existing conditions. Potential morphological impacts of sand mining (sand bed changes) were evaluated only using the relative bed changes; specifically, only the differences in bed change between existing and after-mining conditions were evaluated.

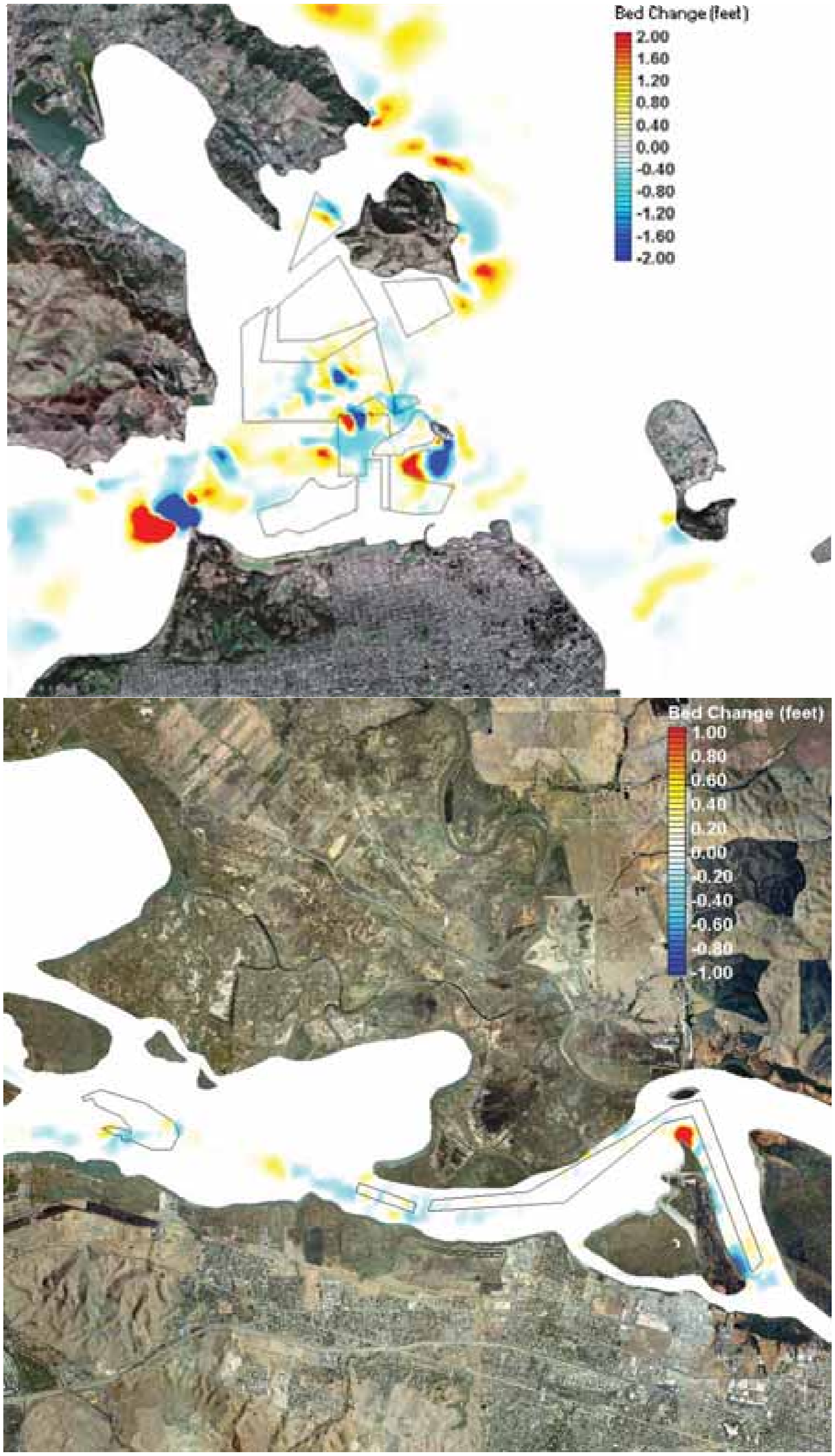

Figure 4-37. One-year existing conditions sand bed changes for Central Bay (top) and Suisun Bay (bottom)

Figure 4-38 shows the relative sand bed changes caused by Scenario 1 (top) and Scenario 2 (bottom) for Central Bay. The relative sand bed changes caused by both scenarios are only measurable within the immediate vicinity of the lease areas.

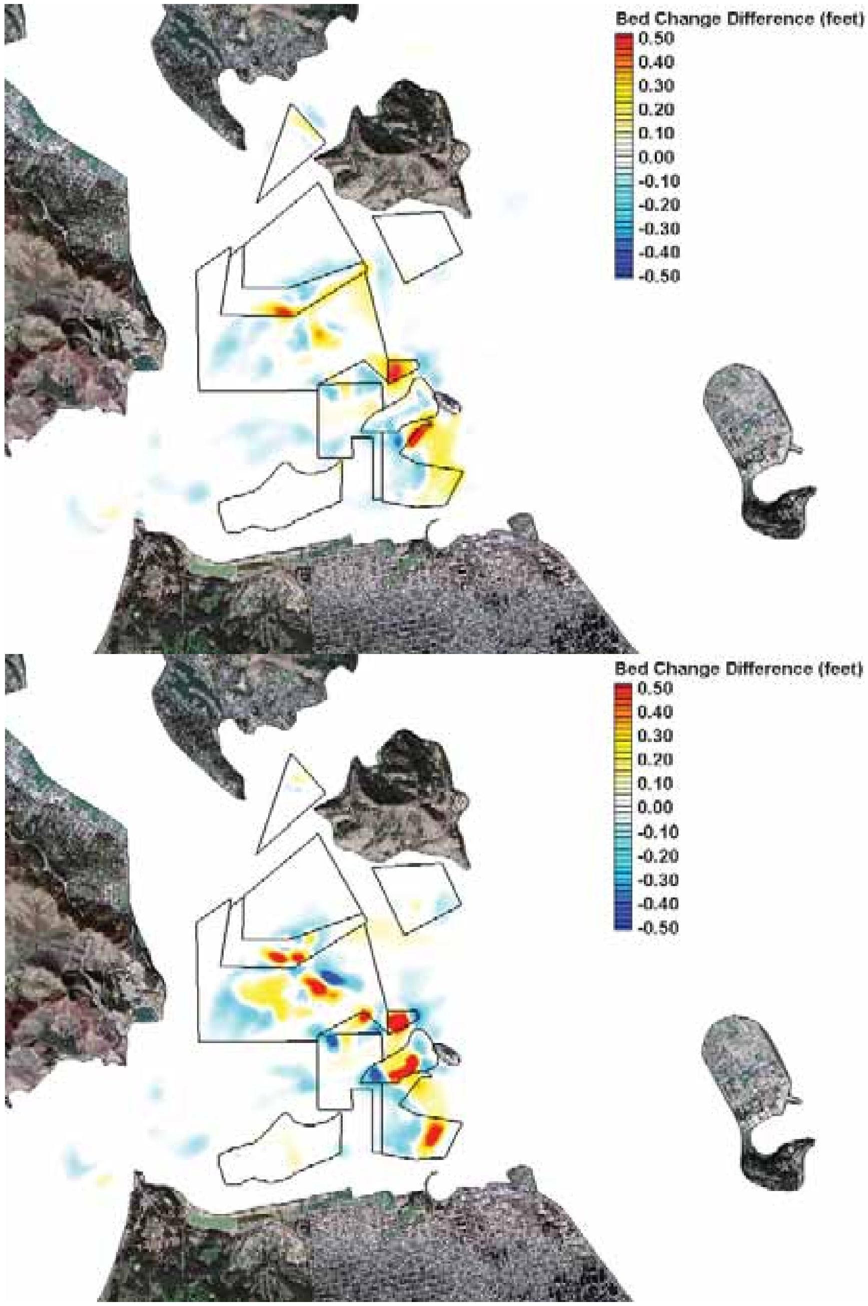

Figure 4-38. One-year sand bed change differences between Scenario 1 and existing conditions (top) and Scenario 2 and existing conditions (bottom) for Central Bay

Figure 4-39 shows the relative sand bed changes caused by Scenario 1 (top) and Scenario 2 (bottom) for Suisun Bay. The relative sand bed changes caused by both scenarios are only measurable within the immediate vicinity of the lease areas.

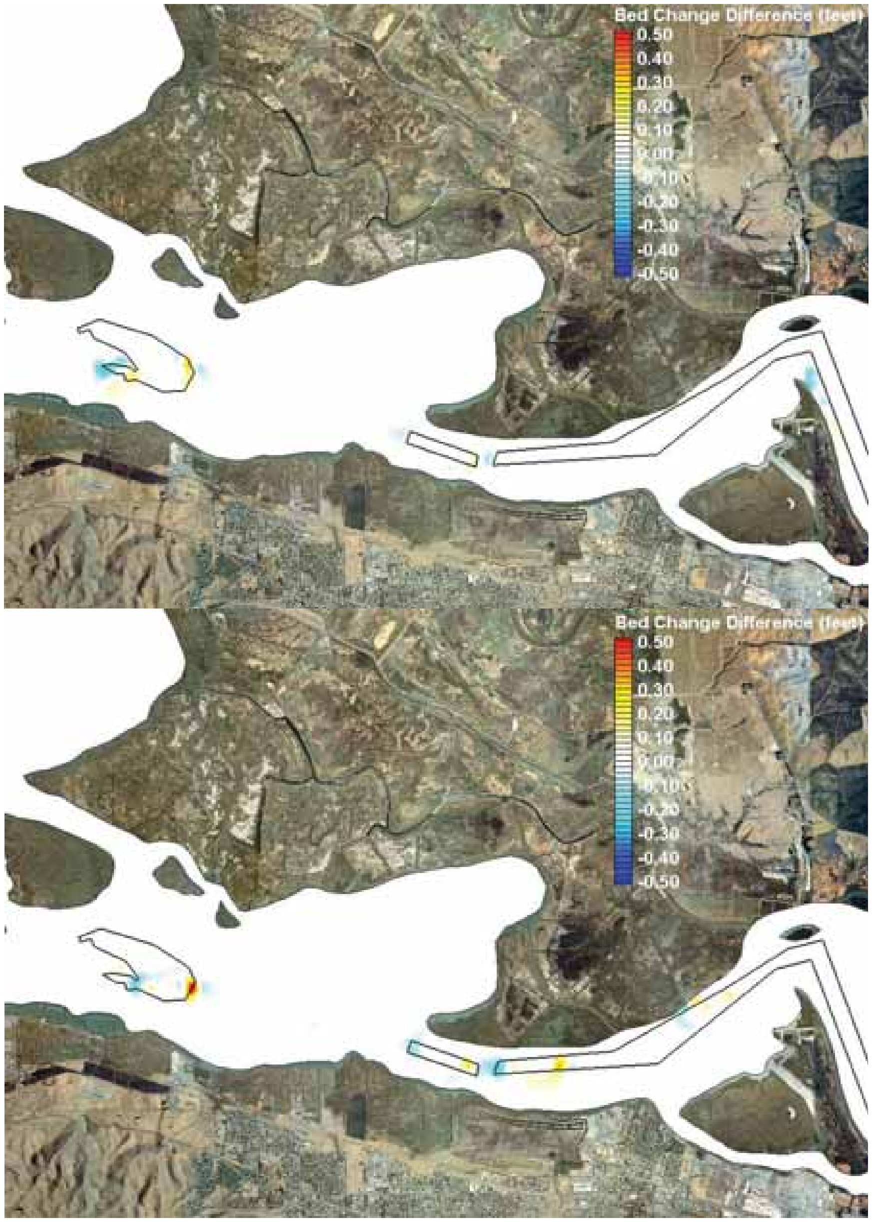

Figure 4-39. One-year sand bed change differences between Scenario 1 and existing conditions (top) and Scenario 2 and existing conditions (bottom) for Suisun Bay

Sediment transport modeling results from both short-term and full-year simulations indicate in a primarily qualitative sense that sand transport and bottom morphology conditions are not likely to be affected by the sand mining activities except in the immediate vicinity of the mining areas.

5. General Conclusions

Conclusions from the coastal engineering analysis are provided in two categories: 1) future sand resources in the mining areas; and 2) impacts to the bay circulation, water quality, and sediment transport/morphology.

5.1. Sand (Sediment) Resources in the Lease Areas

Analysis of bathymetry data and previous mining activities indicates the following with regard to future sand (sediment) resources likely to be present within the lease areas:

- Central Bay: after consideration of actual mining locations and other factors (such as expected bulking after mining), the reported mining volumes are approximately equal to the measured erosion from 1997-2008. This indicates that at least for the purposes of the proposed 10 years of additional mining, Central Bay mining resources are basically limited to sand already in place.
- Suisun Bay: sand mining resources appear to be limited in the deeper areas of Middle Ground, but have not been significantly reduced in West or East Suisun Associates. Sand appears to be primarily arriving in the mining areas under transport from the surrounding areas. The large surrounding areas of ongoing sand transport and lack of observed change in surrounding morphology during the study period indicate that deposition in the mining areas is likely to continue at similar rates.

5.2. Impacts to Bay Circulation, Water Quality and Sediment Transport/Morphology

Analysis of bathymetry data and previous mining activities indicates the following with regard to potential impacts of the proposed 10 years of future sand mining:

- Central Bay: since the vast majority of material removed from Central Bay is still absent from the lease areas and adjacent areas, in general sand impoundment in the mining area holes did not occur. Therefore, the mining areas are not likely to capture sand and induce deficits in other areas resulting in erosion. Analysis of the multibeam survey data indicates that observed bottom erosion migration is limited to the immediate vicinity of the mining areas.
- Suisun Bay: erosion and accretion patterns for most lease and control areas fluctuate with magnitudes larger than the mining volumes; therefore, potential impacts of mining are unclear using survey data alone. Erosion measured in all of the reference sites downstream of the Sacramento River following a large flood event indicates, however, that a steady stream of river sediment is not completely re-supplying the lease areas (hence, the supply is mostly local), and therefore mining impacts to nearby morphology should be re-evaluated following the next 10-year period.

Results of numerical modeling, including hydrodynamics, salinity, and sediment transport/morphology indicate the following with regard to potential impacts of the proposed 10 years of future sand mining:

- Hydrodynamics: Current velocity changes caused by sand mining Scenario 1 or 2 are limited to areas adjacent to the lease areas. Distances from the lease areas where changes in flows are measureable are typically similar to the sizes of the lease areas themselves.
- Salinity: Salinity changes were evaluated in a qualitative manner during short-term simulations by direct comparison of proposed and existing conditions. Some short-term increases in bottom salinity within the mining holes may occur relative to existing conditions. Results indicate that salinity changes outside the immediate vicinity of the lease areas are not likely to occur. Since salinity is directly driven by hydrodynamics, the changes cover roughly the same areas.
- Sediment Transport/Morphology: Sediment transport was evaluated in a qualitative manner through direct comparison of proposed and existing conditions using short-term and full-year simulations. Short-term simulations indicate that the changes in instantaneous transport patterns during both ebb and flood currents are limited to areas immediately adjacent to the lease areas. Full-year simulations indicate that the changes in net transport patterns are also limited to areas immediately adjacent to the lease areas. In addition, comparison of bed changes between existing and after-mining conditions indicates that no morphological impacts (erosion or accretion) are likely outside the immediate vicinity of the mining areas.

6. References

Chen, C., Beardsley, R.C. and G. Cowles. 2006. "An Unstructured Grid, Finite-Volume Coastal Ocean Model." FVCOM User Manual.

Coast & Harbor Engineering. 2000, 2002. Hydrographic Surveys in San Francisco and Oakland, CA.

Hanson Environmental. 2004. "Assessment & Evaluation Of The Effects Of Sand Mining On Aquatic Habitat And Fishery Populations Of Central San Francisco Bay And The Sacramento–San Joaquin Estuary."

Kivva, S.L, Kolomiets, P.S., Shepeleva, T.V. and M.J. Zheleznyak. 2007. "CHEWPCE–MORPH: A Numerical Simulator for Depth-Averaged Surface Water Flow, Sediment Transport and Morphodynamics in Nearshore Zone." Version 2.0.

Luettich, R.A., Jr., Westerink, J.J., and N.W. Scheffner. 1992. "ADCIRC: an advanced three-dimensional circulation model for shelves coasts and estuaries, report 1: theory and methodology of ADCIRC-2DDI and ADCIRC-3DL" Dredging Research Program Technical Report DRP-92-6, U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS, 137p.

Maderich, V. and Brovchenko, I. 2004. "LAGRSED: 2D Lagrangian Sediment Transport Module for CHEWP System".

United States Army Corps of Engineers. 1980 to present. Miscellaneous Hydrographic Surveys.

United States Geological Survey. 1990 to present. Miscellaneous Hydrographic Surveys.

Zhang, J. and A. Baptista. 2005. "A semi-implicit Eulerian-Lagrangian finite-element model for cross-scale ocean circulation, with hybrid vertical coordinates."

APPENDIX A

Representative Project Hydrographic Survey Data Sets

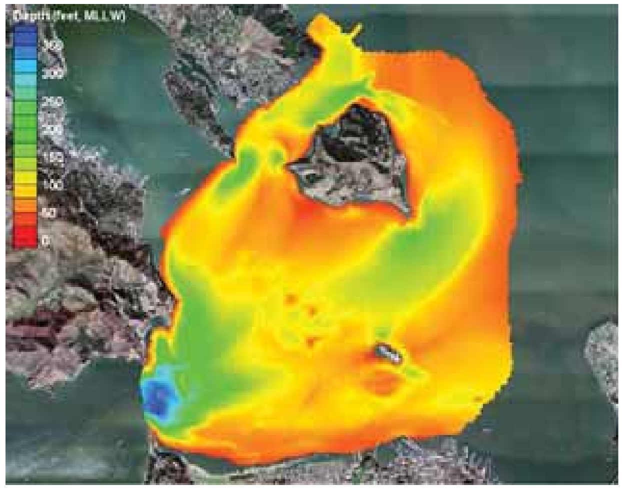

Figure A-1. 2008 USGS multi-beam bathymetry in Central Bay

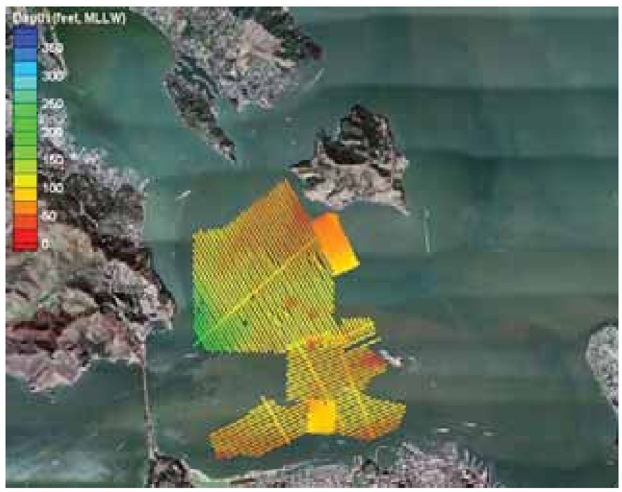

Figure A-2. 2007 E-Trac single-beam bathymetry in Central Bay

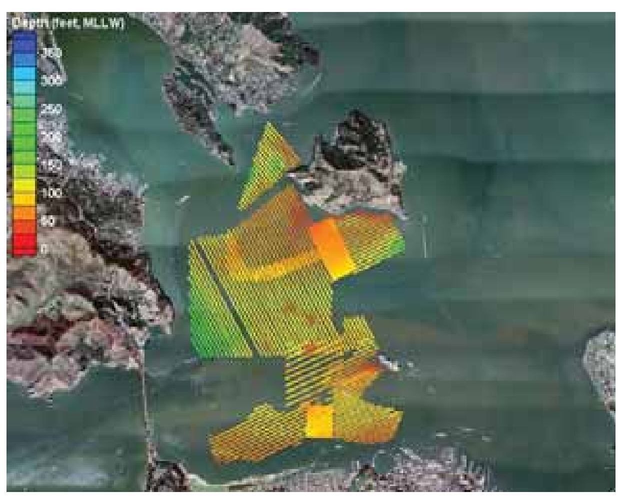

Figure A-3. 2005 PLS single-beam bathymetry in Central Bay

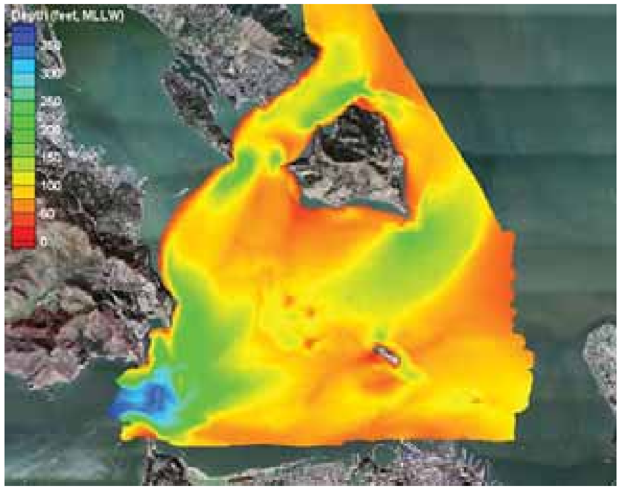

Figure A-4. 1997 USGS single-beam bathymetry in Central Bay

Figure A-5. 2008 USGS multi-beam bathymetry in Suisun Bay

Figure A-6. 2007 E-Trac single-beam bathymetry in Suisun Bay

Figure A-7. 2005 PLS single-beam bathymetry in Suisun Bay

APPENDIX B

Volumes of Available Sediment above -90 ft MLLW and below -3 ft (MLLW) from PLS Surveys for Lease Areas and Control Sites of Central Bay

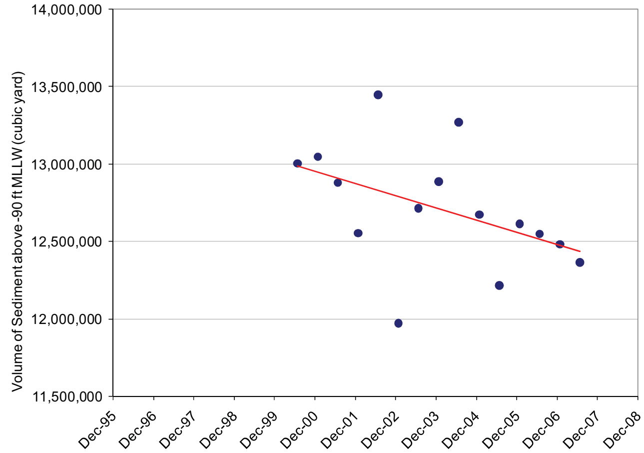

Figure B-1. Volume of available sediment above -90ft MLLW and below -3ft MLLW for Lease Area 709 South

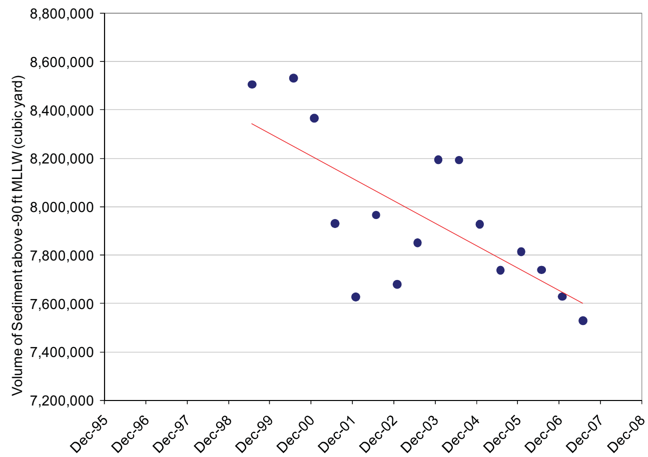

Figure B-2. Volume of available sediment above -90 ft MLLW and below -3 ft MLLW for Lease Area 5871

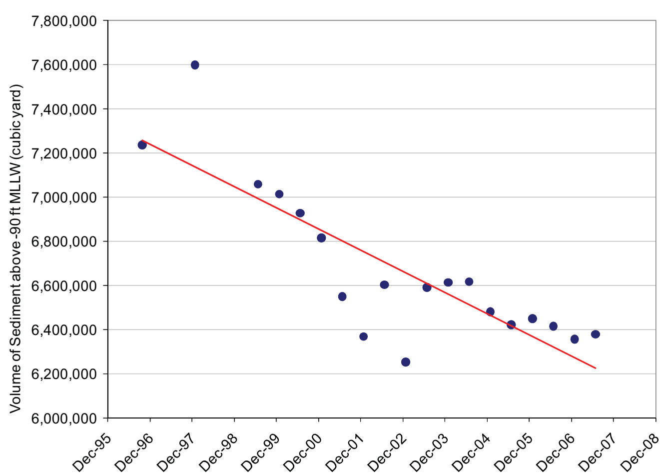

Figure B-3. Volume of Available Sediment above -90ft MLLW and below -3ft MLLW for Lease Area 709 East

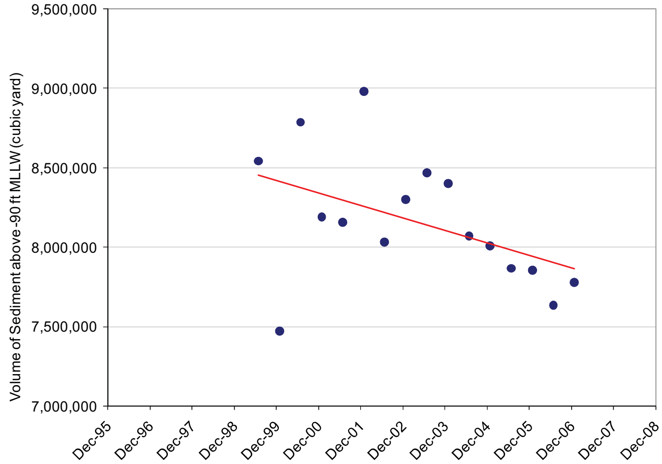

Figure B-4. Volume of available sediment above -90 ft MLLW and below -3 ft MLLW for Lease Area 7780 South

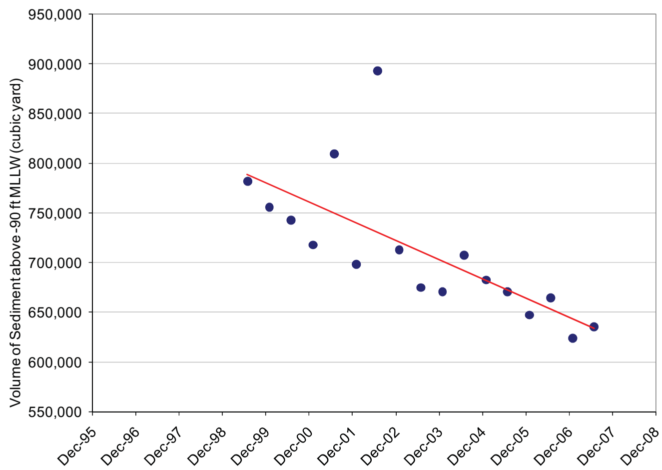

Figure B-5. Volume of available sediment above -90 ft MLLW and below -3 ft MLLW for Lease Area 7780 North

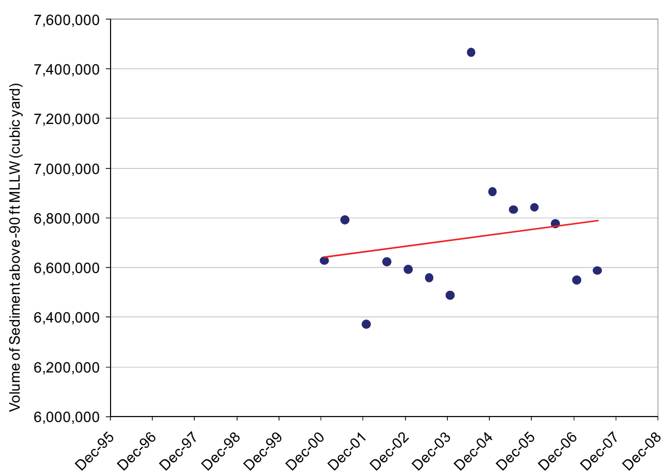

Figure B-6. Volume available sediment above -90 ft MLLW and below -3 ft MLLW for Lease Area 7779 West

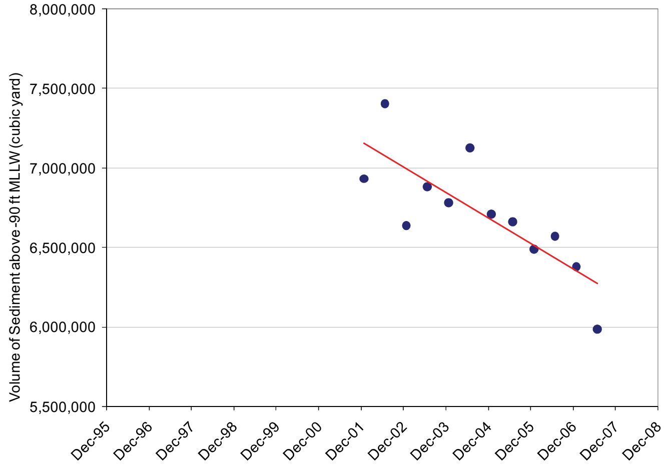

Figure B-7. Volume of available sediment above -90 ft MLLW and below -3 ft MLLW for Lease Area 2036

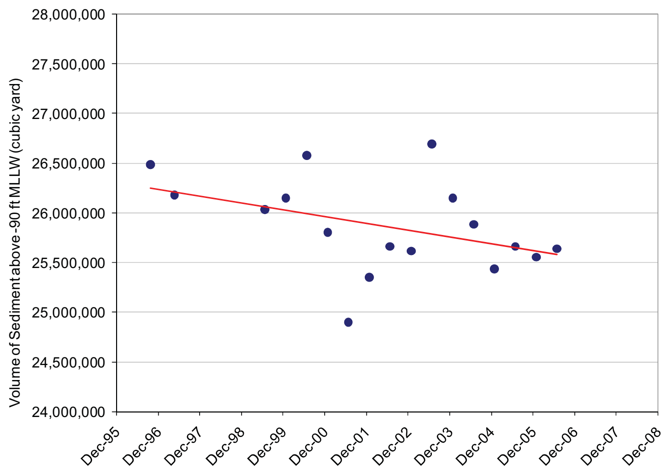

Figure B-8. Volume of available sediment above -90 ft MLLW and below -3 ft MLLW for Lease Area 709 North

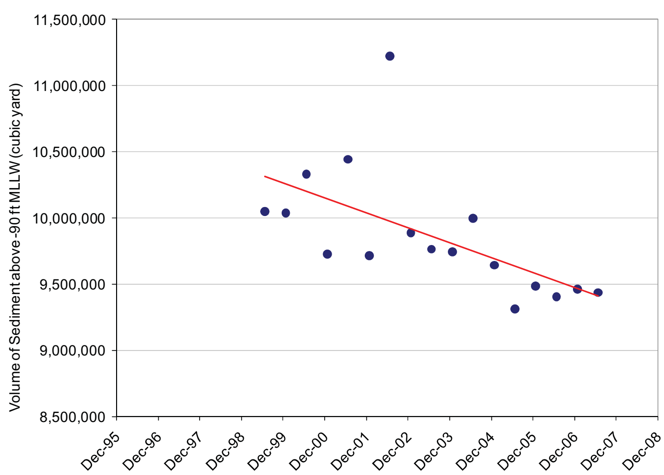

Figure B-9. Volume of available sediment above -90 ft MLLW and below -3 ft MLLW for Lease Area 7779 East

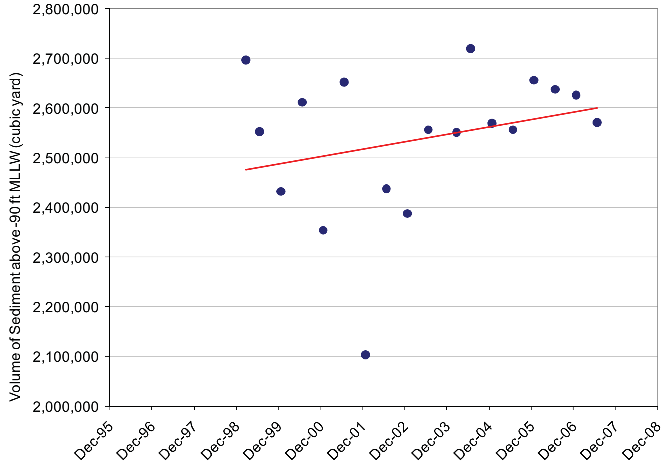

Figure B-10. Volume of available sediment above -90ft MLLW and below -3ft MLLW for Lease Area 7779 North

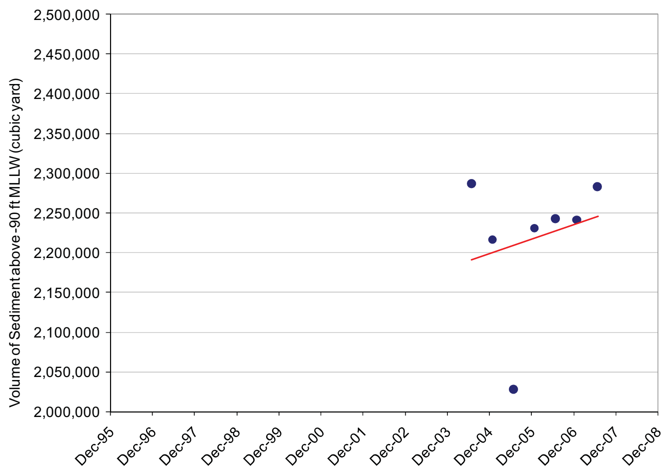

Figure B-11. Volume of available sediment above -90 ft MLLW and below -3 ft MLLW for Control Site North

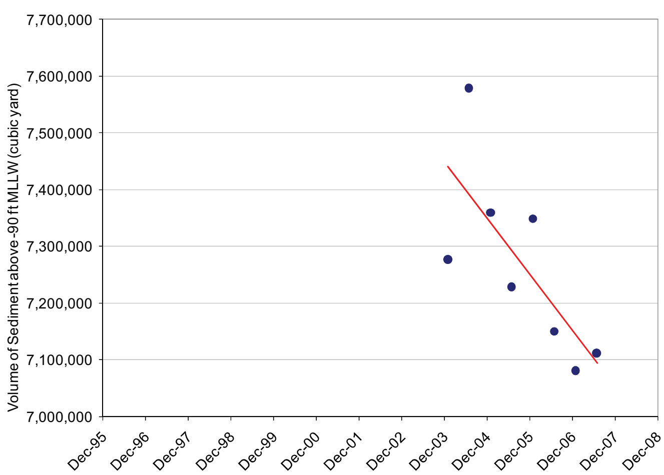

Figure B-12. Volume of Available Sediment above -90 ft MLLW and below -3 ft MLLW for Control Site South

APPENDIX C

Volume of Available Sediment above -90 ft MLLW and below -3 ft MLLW from PLS Surveys for Lease Areas and Control Sites of Suisun Bay

Notes:
Vertical scales of volume plots vary.
Trendlines represent unmodified linear fit.

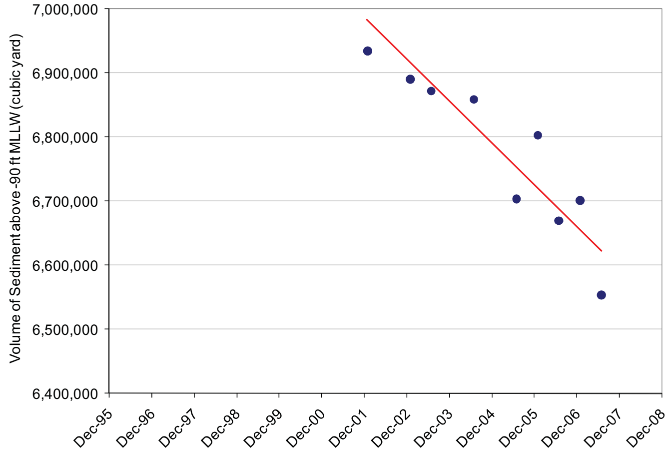

Figure C-1. Volume of available sediment above -90 ft MLLW and below -3 ft MLLW for Lease Area Middle Ground

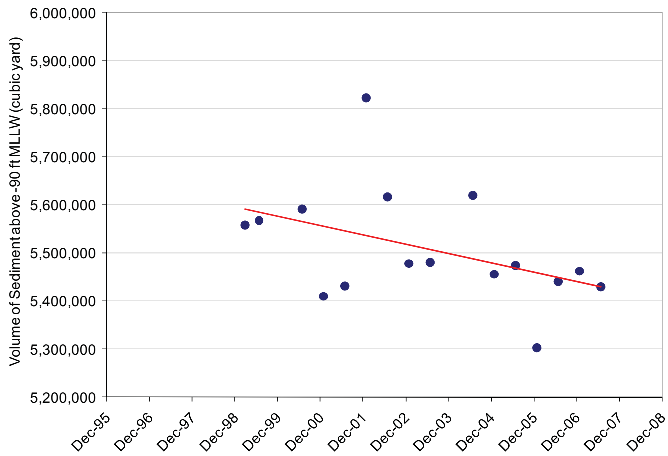

Figure C-2. Volume of available sediment above -90 ft MLLW and below -3 ft MLLW for Lease Area West Suisun Associates

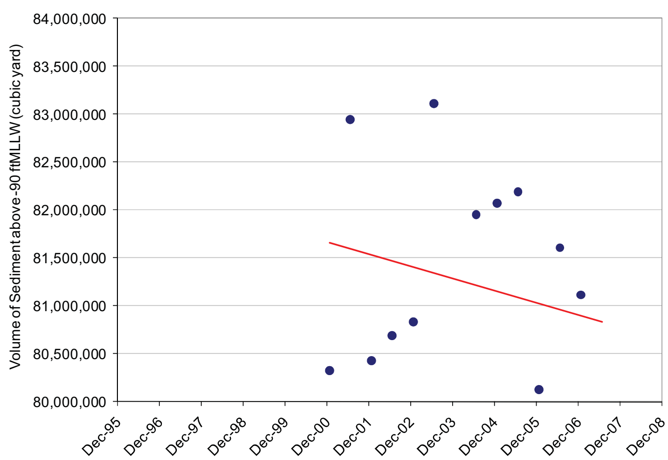

Figure C-3. Volume of available sediment above -90 ft MLLW and below -3 ft MLLW for Lease Area East Suisun Associates

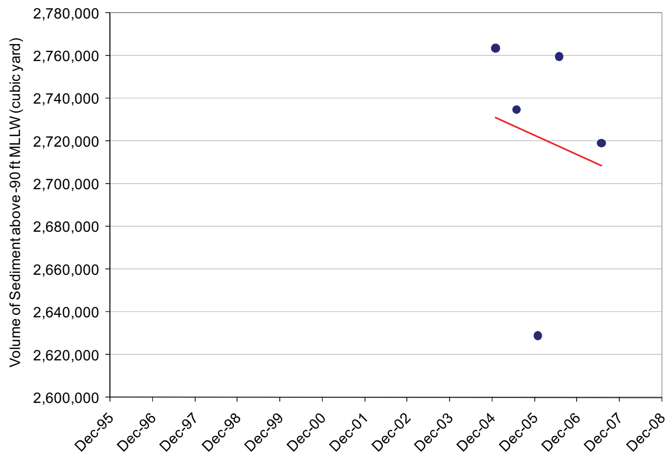

Figure C-4. Volume of available sediment above -90 ft MLLW and below -3 ft MLLW for Control Site 1

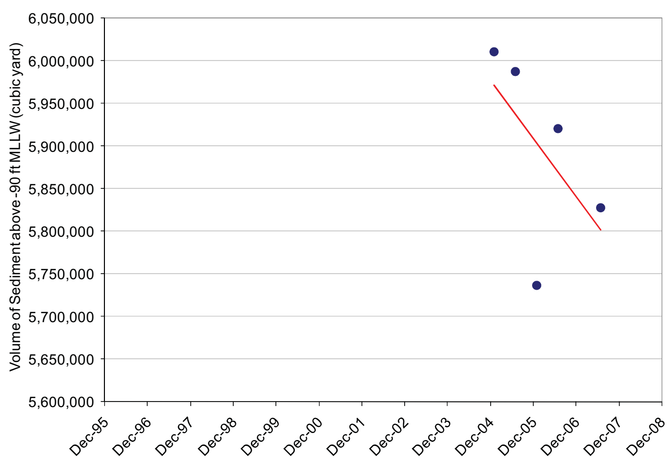

Figure C-5. Volume of available sediment above -90 ft MLLW and below -3 ft MLLW for Control Site 2

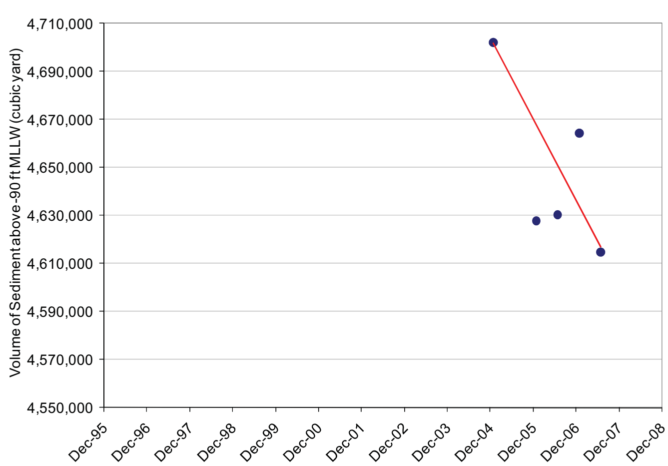

Figure C-6. Volume of available sediment above -90 ft MLLW and below -3 ft MLLW for Control Site 3

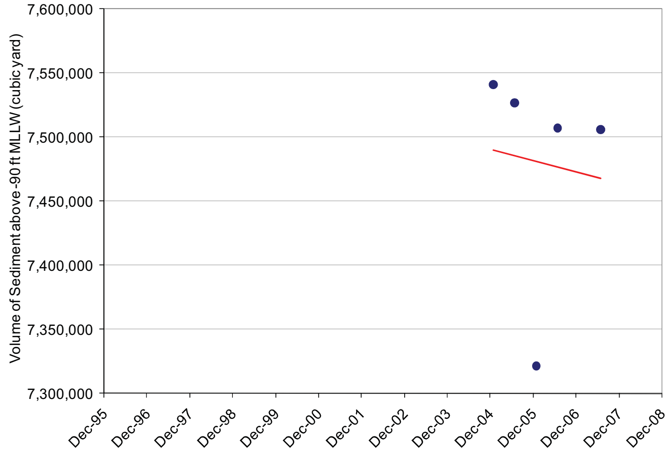

Figure C-7. Volume of available sediment above -90 ft MLLW and below -3 ft MLLW for Control Site 4

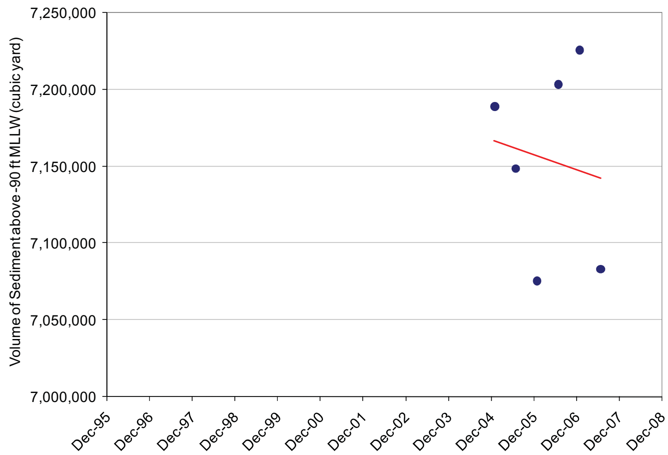

Figure C-8. Volume of available sediment above -90 ft MLLW and below -3 ft MLLW for Control Site 5

APPENDIX D

Numerical Model Development and Verification

D1. Comparison of Results from Numerical Models

Circulation in the Bay is controlled largely by tidal currents and river currents. Changes in circulation are the most important potential impact because circulation in the Bay controls salinity and water quality, as well as sediment transport and bottom morphology in areas outside wave influence. Therefore, analysis of Bay circulation was performed and analyzed with four widely respected numerical modeling tools:

- SELFE (Zhang *et al.*, 2005)
- FVCOM (Chen *et al.*, 2006)
- ADCIRC (Luettich *et al.*, 1992)
- MORPHO-UN (Kivva *et al.*, 2007)

Efforts have been made to use modeling parameters and input data that are as consistent as possible between the modeling tools; however, owing to their fundamentally different theoretical bases and numerical approaches some differences should be expected. Figure D-1 shows velocities computed by SELFE, FVCOM, ADCIRC and MORPHO-UNS during typical flood currents near the Central Bay lease areas. Figure D-2 shows velocities computed by the models during typical ebb currents.

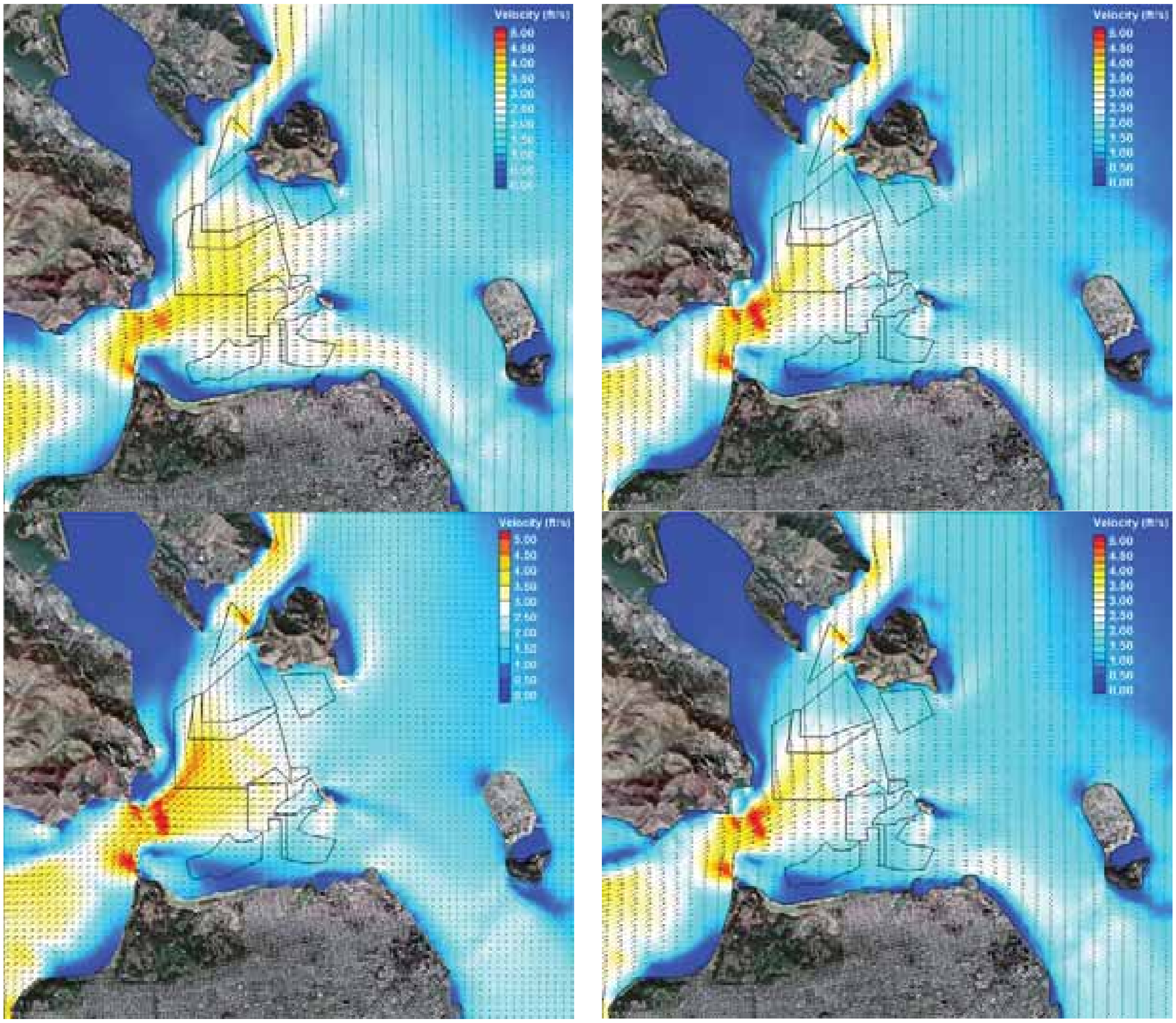

Figure D-1. Typical flood current velocities in Central Bay for SELFE (top left), FVCOM (top right), ADCIRC (bottom left) and MORPHO-UNS (bottom right). SELFE and FVCOM velocities taken at mid-depth, ADCIRC and MORPHO-UNS velocities are depth-averages

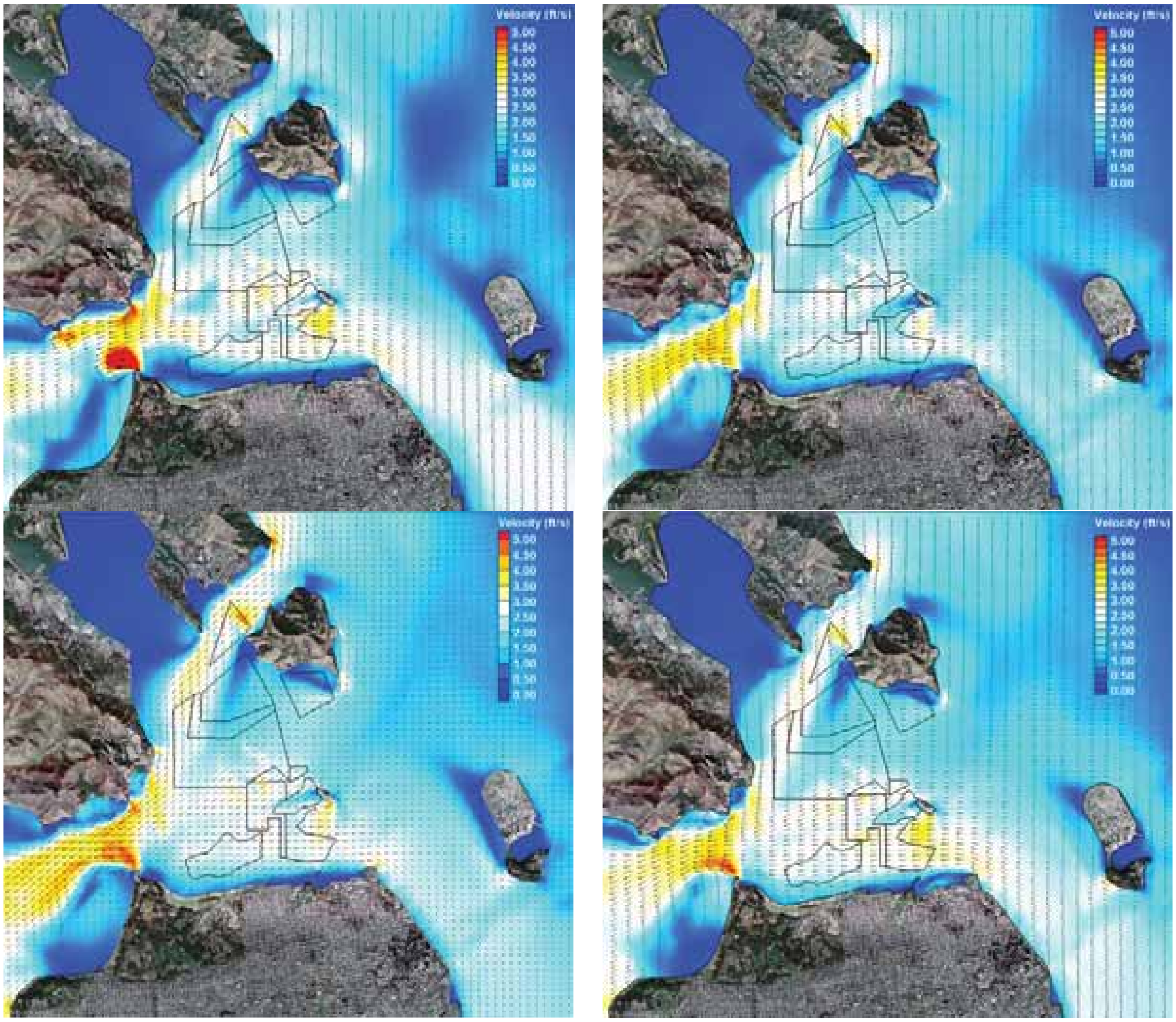

Figure D-2. Typical ebb current velocities in Central Bay for SELFE (top left), FVCOM (top right), ADCIRC (bottom left) and MORPHO-UNS (bottom right). SELFE and FVCOM velocities taken at mid-depth, ADCIRC and MORPHO-UNS velocities are depth-averages

Figures D-3 and D-4 shows the locations where time series of velocities were extracted from the results of all four modeling codes in Central Bay and Suisun Bay, respectively. Figure D-5 shows time histories of mid-depth velocities (for the 3D models) and depth-averaged velocities for the 2D models at Central Bay extraction points 4 (left) and 10 (right) using hydrologic and tide data from early December 1996. The comparison of the four modeling tools indicates that the models provide very similar results, particularly at Point 4 where stronger flows are present. At Point 10, the comparison is reasonable, with SELFE providing the largest current velocities.

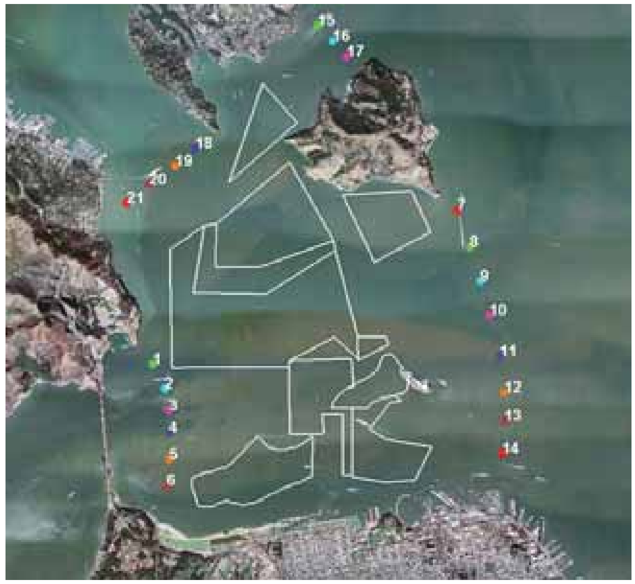

Figure D-3. Locations of time history extraction in Central Bay

Figure D-4. Locations of time history extraction in Suisun Bay

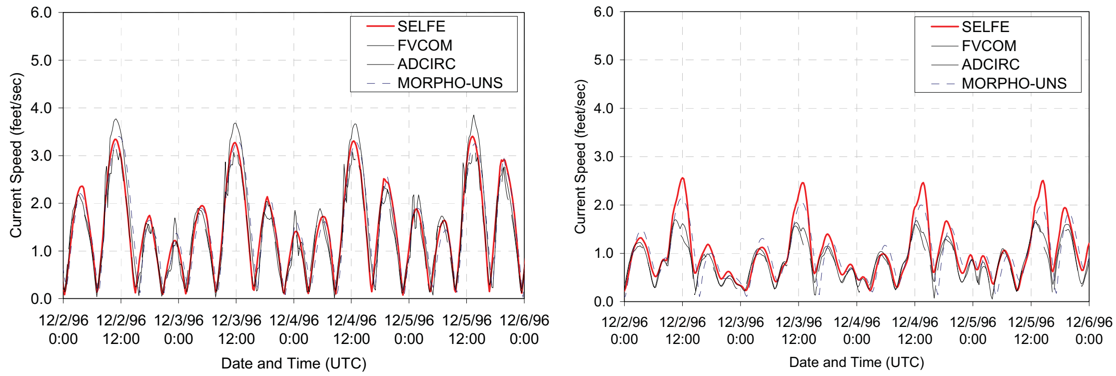

Figure D-5. Velocity time histories in Central Bay at Point 4 (left) and Point 10 (right)

Figure D-6 shows time histories of mid-depth velocities for the 3D models and depth-averaged velocities for the 2D models at Suisun Bay extraction points 24 (left) and 29 (right). The comparison of the four modeling tools indicates that the models provide similar results at both locations, including the phasing and magnitudes of the currents. At Point 24, SELFE often shows the largest current velocities, while at Point 29, ADCIRC shows the largest current velocities.

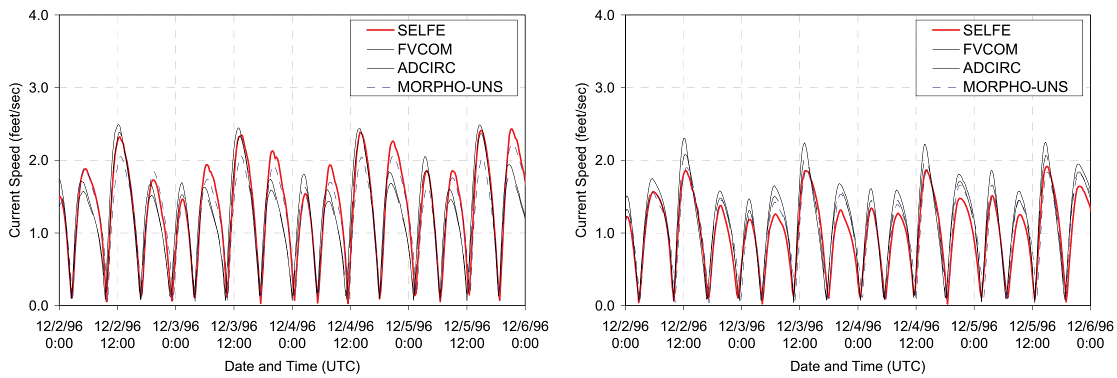

Figure D-6. Velocity time histories in Suisun Bay at Point 24 (left) and Point 29 (right)

The comparison of numerical modeling tools indicated that the four models tested here were likely to provide similar analysis results with regard to potential changes to San Francisco Bay hydrodynamics, and therefore similar conclusions regarding the potential impacts of sand mining. The SELFE model was utilized for all further analysis of potential sand mining impacts due to its good validation with measured currents, concurrent simulation of salinity, and ability to efficiently simulate a full-year period within the project timeframe.

D2. SELFE Model Bathymetry and Domain

Circulation caused by tidal fluctuations within San Francisco Bay is complex. Evaluation of tidal currents within most areas of San Francisco Bay requires modeling the propagation and transformation of tides under the Golden Gate Bridge and through the various channels and shallows of the Bay. The model bathymetry was compiled from various sources, including the following:

- United States Army Corps of Engineers, miscellaneous surveys 1980-present
- United States Geological Survey (USGS), miscellaneous surveys 1990-present
- Coast & Harbor Engineering, Inc. (2000, 2002)
- USGS Multi-beam (1997, 2004, 2008)

The bathymetry data for areas surrounding the lease areas were obtained from the 2008 USGS Multi-beam survey. Inclusion of some rivers entering the estuary, particularly the Petaluma and Napa Rivers, were shown to have a negligible effect on results near the lease areas, and hence these areas were not included in the model. However, the San Joaquin and Sacramento Rivers were added since they contribute the vast majority of discharge into the Bay system. Figure D-7 shows the hydrodynamic modeling domain (left) with bathymetry contours and finite element mesh (right).

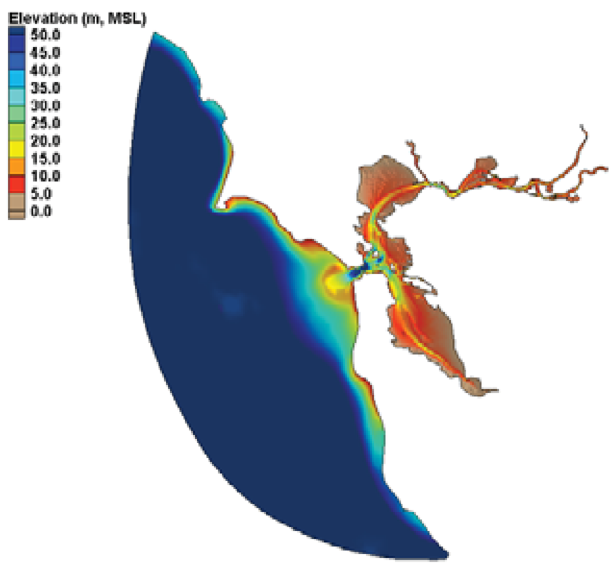

Figure D-7. Bay-wide modeling domain used for SELFE, FVCOM, ADCIRC and MORPHO-UNS simulations (areas inside the Bay shown)

D3. SELFE Model Verification

The bay-wide circulation model was validated using measured currents from the NOAA PORTS station previously in place at the Richmond-San Rafael Bridge. Therefore, only current velocities and water levels were validated for the purposes of the sand mining impact analysis.

Forcing of the San Francisco Bay model requires detailed tidal constituent data at each calculation node along the offshore boundary of the model. Tidal constituent data consists of unique amplitude and phase data for each tidal constituent at each offshore node. For the present analysis, these amplitude and phase data for the largest 13 tidal constituents were obtained from a worldwide database (Le Provost *et al.,* 1994).

Measured current data were available from an Acoustic Doppler Current Profiler (ADCP) deployed from 1999-2002 near the Richmond-San Rafael Bridge (I-580), located at 37°55'45.5"N, 122°25'30.0"W. The ADCP was deployed by NOAA under the PORTS real-time observation network (http://sfports.wr.usgs.gov/SFPORTS/). Predicted tide data were extracted from NOAA data for the Point San Pedro Station (NOAA Station ID 641), located at 37°59'40"N, 122°26'80"W.

The simulation period chosen for validation was a 14-day period beginning on December 18th, 1999 at 00:00 (UTC). No additional boundary conditions were prescribed for the validation period because river flows into the bay were low during this period, and therefore had a negligible effect on current velocities at the Richmond Station location. Modeling parameters such as drag coefficient (0.002) were not altered from previous San Francisco Bay model calibration and verification efforts.

Figure D-8 shows the winter measured and SELFE mid-depth current speeds at the Richmond Gauge, as well as the predicted (NOAA) and SELFE tidal fluctuations at the Point San Pedro Station. The velocities on ebb and flood tide and tidal fluctuations are well predicted by the SELFE model. The SELFE model developed for the project was therefore determined to be a reliable tool for analysis of project circulation, sediment transport, and water quality impacts of the proposed sand mining.

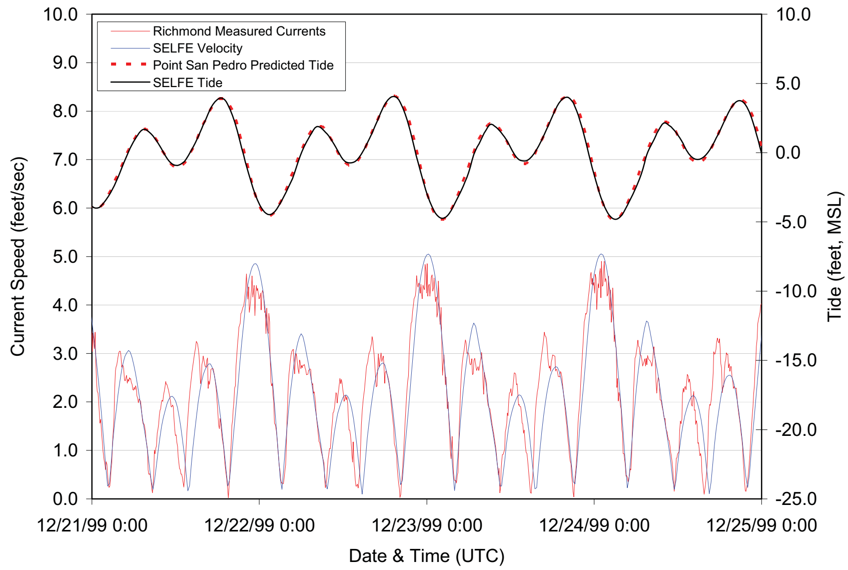

Figure D-8. Measured and predicted (SELFE) tides and currents at Richmond gauge and Point San Pedro gauge (NOAA)

D4. SELFE Model Boundary and Initial Conditions

Boundary conditions relevant to the analysis of sand mining impacts include river discharges (primarily from San Joaquin and Sacramento Rivers), tidal constituents at the Pacific Ocean boundary, and temperature/salinity values at the river/offshore boundaries. Initial conditions consisted of bay-wide temperature and salinity distributions. Temperature and salinity initial and boundary conditions were developed from measurements along a bay-wide longitudinal transect by United States Geological Survey (http://sfbay.wr.usgs.gov/access/wqdata/). Temperature and salinity conditions offshore were taken from concurrent measurements at the San Francisco Buoy by the National Data Buoy Center (Buoy #42068). Temperature and salinity at both the river and offshore boundaries were assumed to be constant during the simulation. Figure D-9 shows the measured salinity and temperature longitudinal transect taken by USGS that was used for modeling initial conditions.

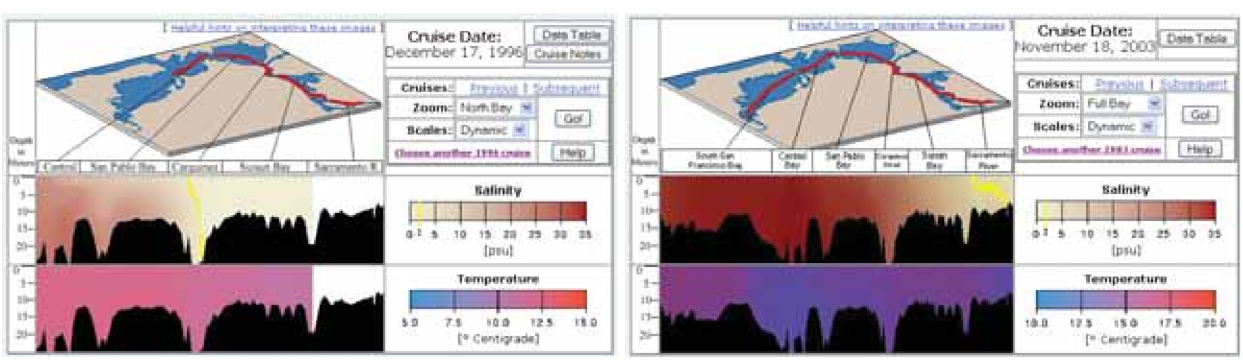

Figure D-9. Measured salinity and temperature used as initial conditions in the simulation; left, 1996 simulation; right, 2003 simulation (www.USGS.gov)

Tidal constituents were taken from the database of Le Provost as described in Section A.1 above. River discharges were taken from the DAYFLOW model (California Department of Water Resources 1978). Total discharge inputs were consolidated into the Sacramento and San Joaquin Rivers which were represented in the model.

D5. Sediment Transport Model Description

Sediment transport in the Bay-Delta estuary was simulated using hydrodynamic data from the 3D SELFE model as input into the LAGRSED model (Maderich *et al.*, 2004). The LAGRSED model is a 2D Lagrangian sediment transport model that was extended by incorporating bottom shear stresses directly from the 3D SELFE model results into calculations of transport. The LAGRSED model was chosen because it can simultaneously simulate multiple grain sizes and utilizes state-of-the-art formulations for transport under various flow conditions. Only sand known to exist in various locations around the Bay was simulated. Areas known to consist of largely Young Bay Mud or rock did not contribute sediment into the simulations but could be used by migrating sand. The LAGRSED model covered the same modeling domain extents as the 3D SELFE model.

D6. Sediment Transport Model Setup and Sediment Information

Multiple different types of boundary conditions were used as input into the LAGRSED model during initial testing, particularly near the river boundaries. Eventually, the boundaries were determined to be sufficiently far from the project site that bedload and suspended load transport develops inside the domain, and no sediment boundary conditions were required. The model was used to calculate transport and morphology for the full one-year simulation starting in December 1996. In order to construct the initial sediment transport modeling domain, numerous sources of sand grain sizes were collected and evaluated (Hanson Environmental 2004, Rubin et al 1979). Figure D-10 shows grain sizes reported in Rubin et al (1979) as an example.

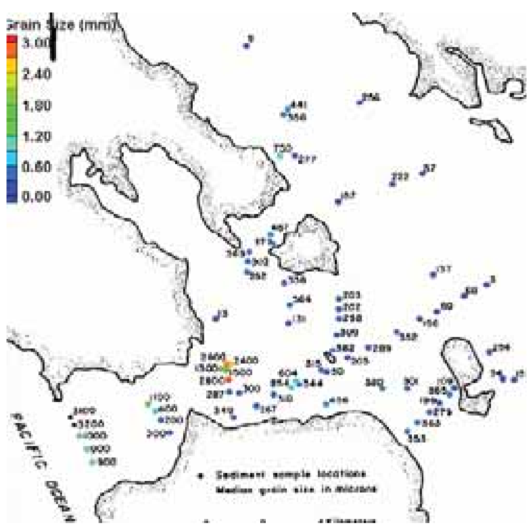

Figure D-10. Central Bay grain sizes (Source: Rubin et al 1979)

Based on evaluation of these data sources and digitization of sampled grain size plots from mining operations provided in Hanson Environmental (2004), CHE developed a bay-wide sediment grid that contains sand type zones in areas known to be sand resource areas. Each of these zones contains a certain gradation of sediment, developed as a set of thousands of individual particles whose sizes are set according to the specified gradation. Figure D-4 shows the sand type zones. Each gradation was assumed to consist of three sediment sizes, centered about the median diameters shown in Figure D-11.

It is immediately clear that significant differences exist in measured sediment sizes even in the same exact location, and even when samples are taken one after another in time. Therefore, it should be understood that the proposed sand distribution is intended to provide qualitative sediment transport information and reasonable predictions only for direct comparison between proposed mining scenarios and existing conditions.

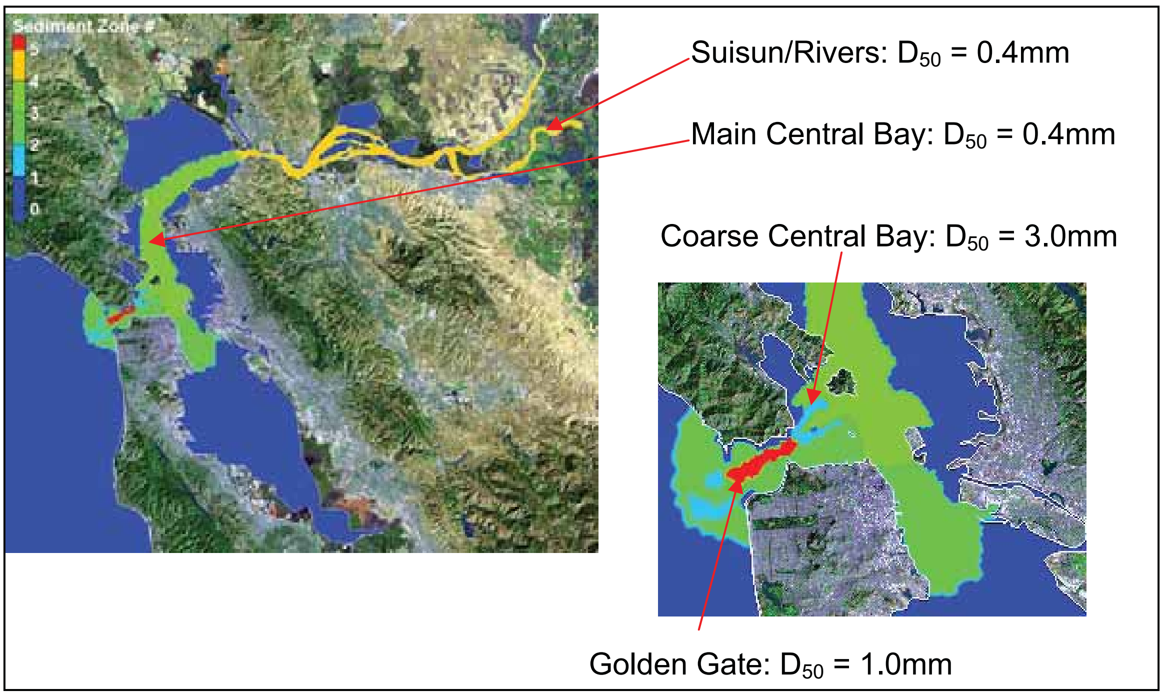

Figure D-11. Sand type zones defined in LAGRSED

D7. References

Chen, C., Beardsley, R.C. and G. Cowles. 2006. "An Unstructured Grid, Finite-Volume Coastal Ocean Model." FVCOM User Manual

Coast & Harbor Engineering, Inc. 2000, 2002. Hydrographic Surveys in San Francisco and Oakland, CA.

California Department of Water Resources. 1978. DAYFLOW Model.

Kivva, S.L, Kolomiets, P.S., Shepeleva, T.V. and M.J. Zheleznyak. 2007. "CHEWPCE–MORPH: A Numerical Simulator for Depth-Averaged Surface Water Flow, Sediment Transport and Morphodynamics in Nearshore Zone." Version 2.0.

Le Provost, C., Genco, M. L., Lyard, F., Vincent, P., and P. Canceil. 1994. "Spectroscopy of the World Ocean Tides from a Finite Element Hydrological Model," J. Geophysical Research, 99, 24777–24798.

Luettich, R.A., Jr., Westerink, J.J., and N.W. Scheffner. 1992. "ADCIRC: an advanced three-dimensional circulation model for shelves coasts and estuaries, report 1: theory and methodology of ADCIRC-2DDI and ADCIRC-3DL." Dredging Research Program Technical Report DRP-92-6, U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS, 137p.

Maderich, V. and Brovchenko, I. 2004. "LAGRSED: 2D Lagrangian Sediment Transport Module for CHEWP System".

National Data Buoy Center. 1996. Water temperature and salinity measurements at the San Francisco Buoy #46028.

Rubin, D.M. and D.S. McCulloch. 1979. "The movement and equilibrium of bedforms in Central San Francisco Bay". pp 97-113 In T.J. Conomos (ed), San Francisco Bay – The Urbanized Estuary. Pacific Division Amer. Assoc. Advance. Sci. San Francisco, CA.

United States Army Corps of Engineers. 1980-present. Miscellaneous Hydrographic Surveys.

United States Geological Survey. 1990-present. Miscellaneous Hydrographic Surveys.

United States Geological Survey. 1996. Water Quality Measurements in the San Francisco Bay Estuary (http://sfbay.wr.usgs.gov/access/wqdata/).

Zhang, J. and A. Baptista. 2005. "A semi-implicit Eulerian-Lagrangian finite-element model for cross-scale ocean circulation, with hybrid vertical coordinates."

THIS PAGE INTENTIONALLY LEFT BLANK