Appendix G

BATHYMETRIC AND HYDRODYNAMIC STUDY

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SAND MINING RESOURCE EVALUATION AND IMPACT ANALYSIS

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ENGINEERING

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SAND MINING RESOURCE EVALUATION AND IMPACT ANALYSIS

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COAST & HARBOR ENGINEERING

Sand Mining Resource Evaluation and Impact Analysis

Executive Summary

Coastal engineering analysis was performed by Coast & Harbor Engineering, Inc. (CHE) as a subconsultant to Environmental Science Associates (ESA) under contract with California State Lands Commission (CSLC) to evaluate potential future sand resources within certain Central Bay and Suisan Bay sand mining lease areas, as well as the potential impacts of the proposed mining lease renewal for the next 10 years. The study consisted of morphological analysis and hydrodynamic modeling, and covered a wide spectrum of physical processes including tidal and river circulation, salinity, sediment transport, and morphology.

Morphological analysis indicates a measurable depletion of sand resources in the Central Bay lease areas. The vast majority of sediment mined from these areas during the past decade is still missing from the lease and immediately adjacent areas. It appears that recovery of the Central Bay sand mining leases in Central Bay is a long-term process. The study indicates that for the purposes of the proposed 10-year mining lease renewal, sand mining resources in Central Bay are largely limited to material already in place.

In addition, analysis indicates that the proposed additional 10 years of sand mining in the Central Bay lease areas is not likely to cause a significant impact on sediment transport and budgets in areas outside the immediate vicinity of the lease areas, such as the San Francisco Bar, Ocean Beach, etc. It appears that only small amounts of sediment have been impounded in the mining holes. Numerical modeling results indicate that changes in hydrodynamics, salinity and sediment transport/morphology are likely to be confined to the immediate vicinity of the mining areas.

In Suisun Bay, for the majority of lease areas sand mining resources are relatively stable and were not noticeably depleted in the period 2004 to 2008. However, in the deeper areas of the Middle Ground (TLS39) lease area, sand resources appear to have been measurably depleted and for the short-term, sand for mining is likely to be limited to material that is already in place. It appears that the proposed 10 years of further sand mining in the Suisun Bay lease areas and control sites is not likely to cause measurable impacts (in terms of sediment loss) to the surrounding areas. Numerical modeling results for Suisun Bay indicate that changes in hydrodynamics, salinity and sediment transport/morphology are likely to be confined to the vicinity of the mining areas.

Although analysis indicates that significant impacts are not likely to exist outside the immediate vicinity of the lease areas, analysis for both Central Bay and Suisun Bay sites should be repeated prior to subsequent renewal of the sand mining lease.

Sand Mining Resource Evaluation and Impact Analysis

1. Introduction

The following coastal engineering analysis was performed by Coast & Harbor Engineering, Inc. (CHE) as a subconsultant to Environmental Science Associates (ESA) under contract with California State Lands Commission (CSLC) to evaluate potential future sand resources within certain specified CSLC lease areas and the potential impacts of the proposed mining lease renewal for the next 10 years. The study consisted of analysis of bathymetry changes for the purpose of evaluating future sand resources availability and potential impacts of mining, as well as numerical modeling to determine potential impacts of mining on San Francisco Bay circulation, water quality, and sediment transport/morphology.

2. Description of Proposed Sand Mining

Sand mining is proposed to occur within designated CSLC lease areas using a variety of dredging methods over the next 10-year period to maximum depths of 90 feet (MLLW, Hanson Environmental 2004). The lease areas in Central Bay and Suisun Bay are shown in Figures 2-1 and 2-2, respectively. Table 2-1 shows the proposed annual mining volumes for the next 10 years provided to CHE by ESA.

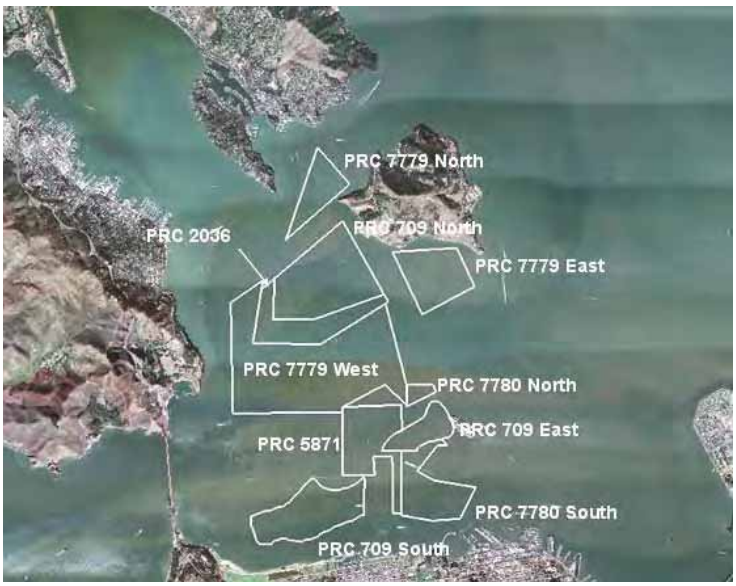

Figure 2-1. Central Bay lease areas (Note: no mining is proposed in lease area PRC 5871 during the next 10 years)

Figure 2-2. Suisun Bay lease areas

Table 2-1. Proposed Annual Mining Volumes by Lease Area

Lease Area	Requested Amended Volume (cy)
PRC 709.1	340,000
PRC 2036.1	450,000
PRC 7779.1	550,000
PRC 7780.1	200,000
Suisun Associates (East and West)	300,000
Middle Ground (TLS 39)	200,000

In addition to the lease areas, a series of control sites were surveyed (PLS surveys, see Section 3.1) to be used as a control site for sand resource availability and morphology analysis (see Figures 2-3 and 2-4).

3. Analysis of Sand (Sediment) Resource Availability and Bottom Morphology

3.1. Project Bathymetry Data

Many different bathymetry data sets exist in San Francisco Bay. However many of these data sets have insufficient spatial coverage and do not cover the period of interest when sand mining occurred and was documented. Evaluation of *sand* resource availability is not feasible without field data collection (borings), which are beyond the scope of this analysis. Instead, the analysis that was conducted evaluated the *sediment* availability in the lease areas purely in terms of material volumes. For analysis of sediment availability, bathymetry data sets covering the specific lease

areas of interest were provided by CSLC. The bathymetry data sets used for analysis are shown in Table 3-1.

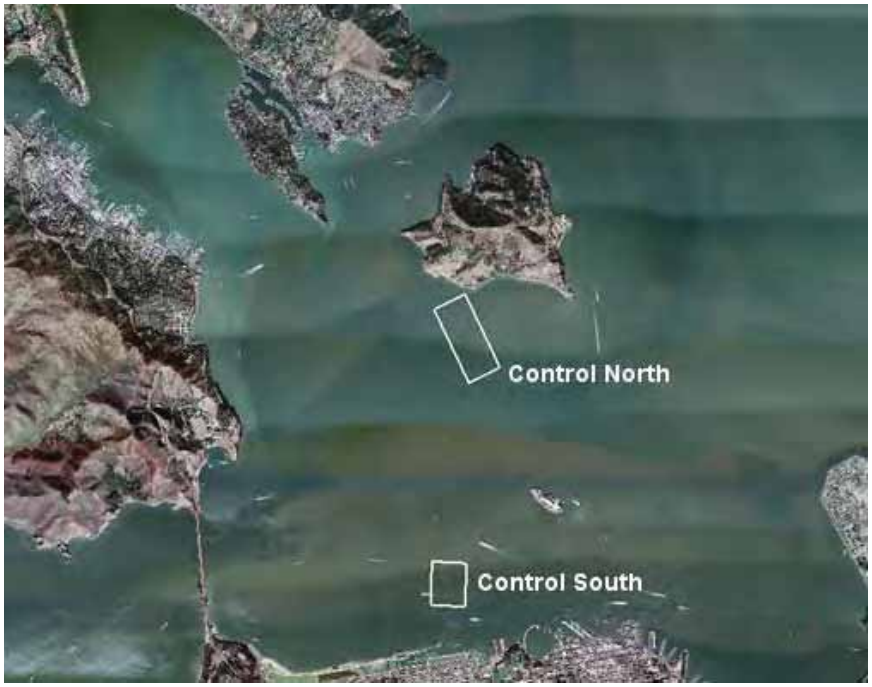

Figure 2-3. Control sites in Central Bay

Figure 2-4. Control sites in Suisun Bay

Table 3-1. Bathymetry Data Sets used for Analysis

Source	Type	Period	Coverage
USGS	Multi-beam	2008	Central Bay / Suisun Bay
E-Trac	Single-beam	2007	Central Bay / Suisun Bay
USGS	Multi-beam	1997	Central Bay
PLS	Single-beam	1996 - 2007	Central Bay / Suisun Bay

Appendix A shows color-contour representations of all bathymetry data sets used for analysis in both Central Bay and Suisun Bay. The bathymetry data were quality-checked and processed in order to perform analysis of the past and present available sediment resources in Central San Francisco Bay and Suisun Bay lease areas.

PLS single-beam data were available at six-month intervals for the period 1996-2007 for the Central Bay and Suisun Bay lease areas. These survey data sets were used for the analysis of mining resources due to their high frequency and consistency to identify possible trends in reduced/increased availability of sediment in the lease areas. From the series of PLS bathymetry data, the volumes of sediment above bottom elevation -90 feet (MLLW) and below bottom -3 feet (MLLW) were calculated from each survey for each lease area and used to define the volume of sediment available for mining. These elevations were determined based on mining operational constraints (Hanson Environmental 2004).

3.2. Central Bay Sand Resource Availability

Figure 3-1 shows the evolving volume of available sediment in lease area PRC 2036 between December 2001 and June 2006 as an example. During this period, this lease area (which was heavily mined) lost on average approximately 2.3% of its total sediment on an annual basis. Appendix B provides plots with available sediment volumes from each of the available bathymetry surveys for all lease areas and control sites of Central Bay.

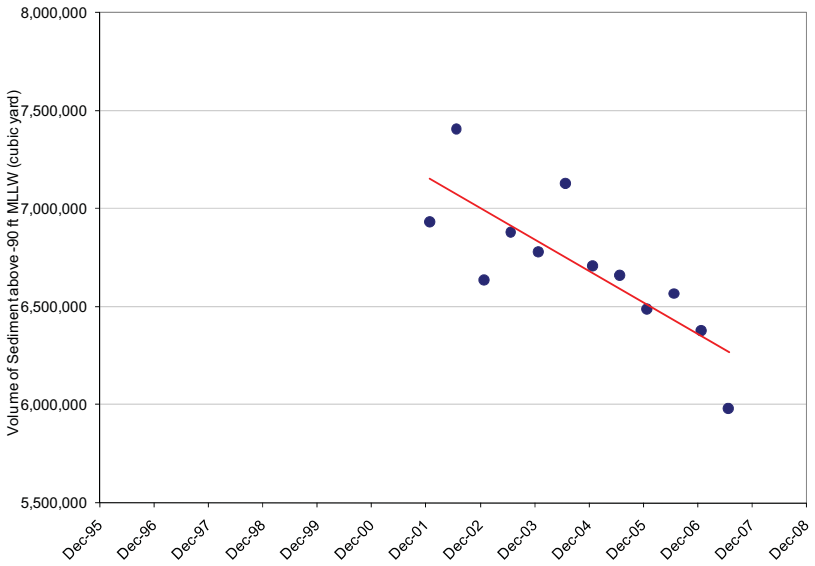

Figure 3-1. Volume of Available Sediment in Lease Area 2036

Bathymetry data analysis indicates recognizable trends of reduced sediment availability in most of the lease areas of Central Bay. Linear trend fits of the calculated sediment volumes shows that availability is reduced at rates between 0.6% and 2.5% per year (see Table 3-2). These relatively strong trends are clearly related to mining operations in the lease areas. Lease areas 7779 West and 7779 North do not seem to show clear trends of reduced sediment availability. This is because Lease area 7779 West is a very large area and mining occurred only in a limited portion of the area (Hanson Environmental 2004). Therefore the effects of mining are likely to have been hidden by natural sediment transport processes and survey/volume calculation uncertainties.

Lease area 7779 North shows no erosive trend because it was actually never mined (CSLC, personal communication 2008). The control site North shows a trend of reduced sediment availability (reduction equal to -1.4% per year), while control site South does not show any recognizable trend. Hanson Environmental (2004) shows that sand mining actually did occur within the control site North; therefore, the reduced sediment availability trend in this area is also likely related to sand mining operations in the control site and likely migration of mining holes from the two lease areas on either side (PRC 709 North and PRC 7779 East). Control site South was apparently never mined. In general, areas that were mined show clear erosion trends, and sites that were not mined do not show clear trends.

Table 3-2. Yearly Rate of Sediment Volume Change for Central Bay Lease Areas and Control Sites

Lease Area	Yearly Rate of Sediment Volume Change (%)
PRC 709 South	-0.6
PRC 5871	-1.0

Lease Area	Yearly Rate of Sediment Volume Change (%)
PRC 709 East	-1.3
PRC 7780 South	-0.9
PRC 7780 North	-2.5
PRC 7779 West	+0.3
PRC 2036	-2.3
PRC 709 North	-0.4
PRC 7779 East	-1.1
PRC 7779 North	+0.5
North Control	-1.4
South Control	+0.8

3.3. Suisun Bay Sand Resource Availability

Appendix C provides plots of the total available sediment volumes for all surveys for all lease areas and control sites of Suisun Bay. From the analysis of available sediment trends from PLS surveys, there is a recognizable trend of reduced sediment availability in the deeper parts of the Middle Ground (TLS39) lease area of approximately 1.0% per year. The Suisun Associates lease areas (West and East) do not show a clear trend in reduced sediment availability. Control Site 2, located upstream of the mining areas in the Sacramento River at the confluence with the San Joaquin River, shows a clear trend of ongoing erosion. There appears to be deepening occurring at this control site, however the calculated sediment volumes over time at the other control sites contain significant scatter and therefore trends are difficult to discern.

4. Analysis of Sand Mining Impacts

Sand mining impacts were evaluated in terms of changes in bay hydrodynamics, salinity, and sediment transport/morphology outside the lease areas. Two types of analysis were used to evaluate potential impacts outside the lease areas:

- Bottom morphology change analysis using hydrographic survey data. Potential impact analysis based on bathymetry change was conducted using the hydrographic survey data described in Section 3.
- Numerical modeling of currents, salinity and sediment transport/morphology. Impacts were evaluated by direct comparison of hydrodynamics, salinity and sediment transport/morphology for existing conditions and two after-mining scenarios.

4.1. Sand Mining Impact Evaluation from Measured Bathymetry Changes

Bathymetry/morphology changes in Central Bay and Suisun Bay were analyzed with the bathymetry data sets made available for the project to determine if sand mining is likely to cause potential impacts to Central and Suisun Bays. The morphology analysis was performed with the goal of determining if other areas away from the lease areas, such as the San Francisco Bar or Ocean Beach, could be deprived of natural sediment delivery due to mining operations. Bathymetry changes were calculated using the most consistent data sets with most complete coverage that spanned the longest time periods. As described in Section 3, hydrographic survey data from multiple sources were compiled, processed, filtered, and gridded to develop realistic bottom surfaces from which volume changes could be calculated.

4.1.1. Central Bay

Impact analysis from Central Bay bathymetry changes was most readily performed using the multi-beam data sets because they cover all the lease areas. USGS multi-beam data from 1997 and 2008 provided a highly detailed map of bottom elevation and map of bottom changes. Figure 4-1 shows the 1997 (top) and 2008 (bottom) multi-beam survey data sets.

Figure 4-2 shows the bottom changes since 1997, along with the lease areas and with sand mining "worm tracks," or GPS coordinates of actual mining event locations. Mining also occurred in other areas and the "worm tracks" are not a complete record. However, a clear correlation appears between measured erosion and locations of mining events. Hanson Environmental (2004) shows that in the period 1997-2004, mining operations were also conducted in areas slightly outside of the lease areas. After evaluating the volume bed changes in the lease areas on Central Bay and in these mined areas outside of the lease areas, a total bed erosion of approximately 11.6 million cubic yards (cu yd) was estimated during the period 1997-2008. Table 4-1 shows volumetric bed change results within each specific lease area.

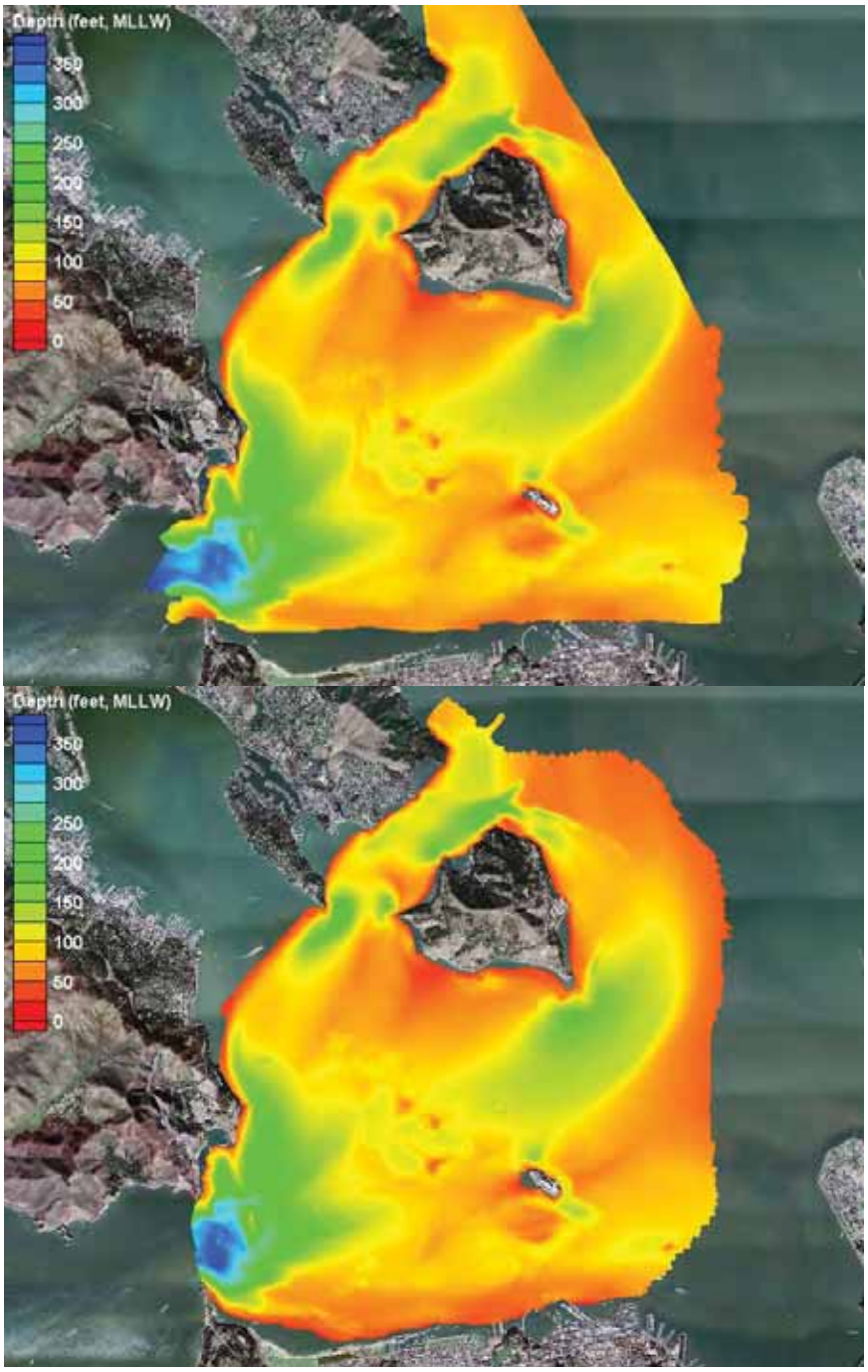

Figure 4-1. Central Bay depths from 1997 (various dates, top) and 2008 (various dates, bottom) USGS multi-beam bathymetry data sets (aerial photo USGS 2004)

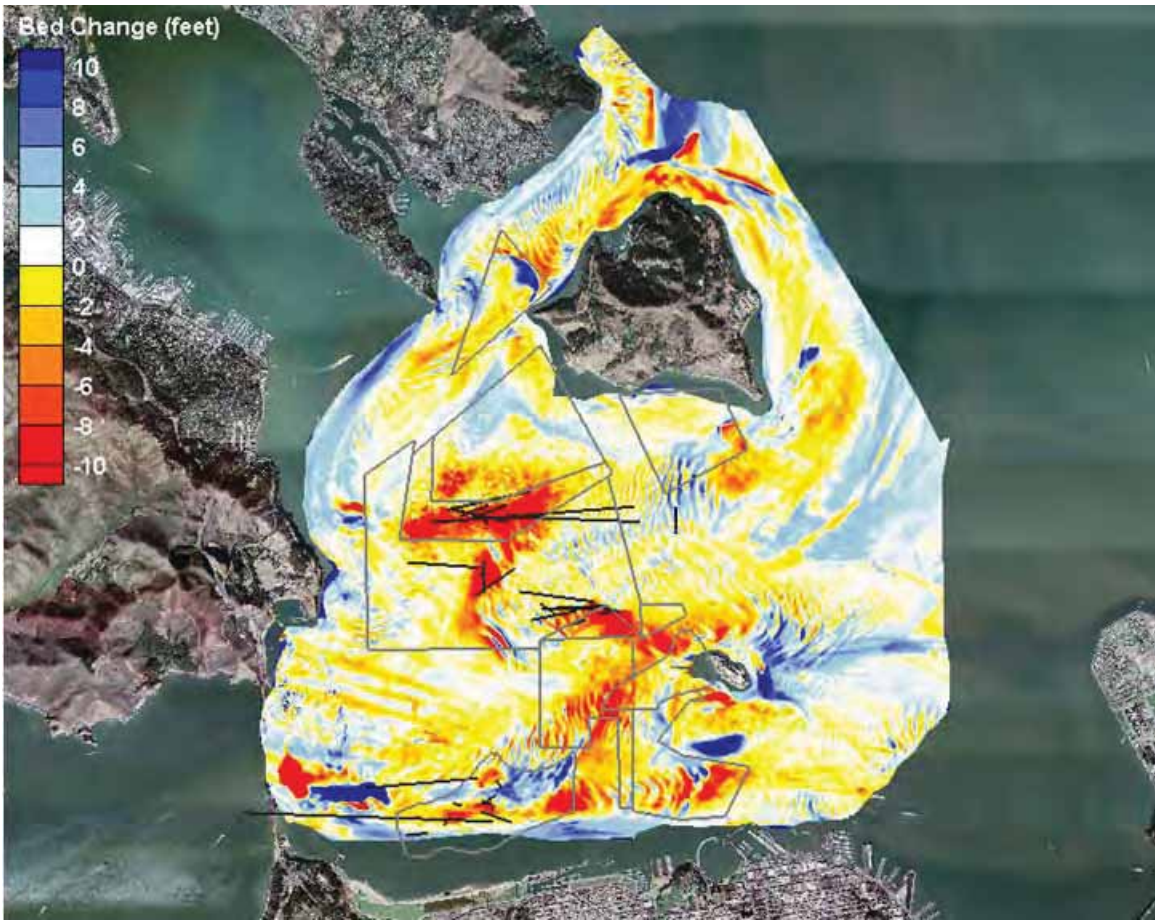

Figure 4-2. Central Bay depth changes between 1997 and 2008 calculated from USGS multi-beam bathymetry data sets (aerial photo USGS 2004) with sand mining location "worm tracks"

Table 4-1. Bed Volume Change for Lease Areas in Central Bay (1997 to 2008)

Lease Area	Bed Erosion (cubic yards)
PRC 709 SOUTH	-450,000
PRC 5871	-1,258,000
PRC 709 EAST	-670,000
PRC 7780 SOUTH	-834,000
PRC 7780 NORTH	-175,000
PRC 7779 WEST	-3,358,000
PRC 2036	-2,658,000
PRC 709 NORTH	-828,000
PRC 7779 EAST	-46,000
PRC 7779 NORTH	-88,000
Areas outside lease areas	-1,235,000
Total Central Bay	-11,600,000

Considering that the erosion volume within the lease and immediately adjacent areas was approximately 11.6 million cubic yards during this period, and that the sand miners reported a total Central Bay dredging volume of 13.5 million cubic yards (as reportedly measured in the barges after bulking), and considering a likely bulking factor on the order of 10%, the volume of material that was reported to have been mined during this period is nearly equivalent to the measured erosion inside and surrounding the lease areas. According to this calculation, only approximately 5% of the material in the lease areas that was mined has been replaced by natural processes. This indicates the following:

- Net bottom erosion due to sand mining has largely been contained within the lease and immediately adjacent areas. This indicates that the mining holes migrated/expanded only over short lateral distances, and erosion of adjacent areas did not spread outside the immediate vicinity of the lease areas.
- Since the vast majority of the mined material has been accounted for immediately adjacent to the lease areas, it appears that sand mining in Central Bay is not likely to cause measurable sediment depletion in areas outside the mining areas, such as the San Francisco Bar, Ocean Beach or other areas.
- Since mining in the lease areas beyond what was evaluate here could be expected to further deepen the holes and potentially attract more sediment in the future, analysis should be performed prior to subsequent lease renewal periods.

4.1.2. Suisun Bay

In Suisun Bay, only one USGS multi-beam data set was available (2008). Bottom changes were developed using a combination of the 2008 multi-beam data and the 2007 E-Trac single-beam data (2007). Figure 4-3 shows the 2008 multi-beam (left) and 2007 single-beam (right) survey data sets. Due to the consistency in the data sets and type of data and lack of earlier consistent data, only the PLS survey data sets between 2004 and 2007 were used for analysis of ongoing morphology in Suisun Bay.

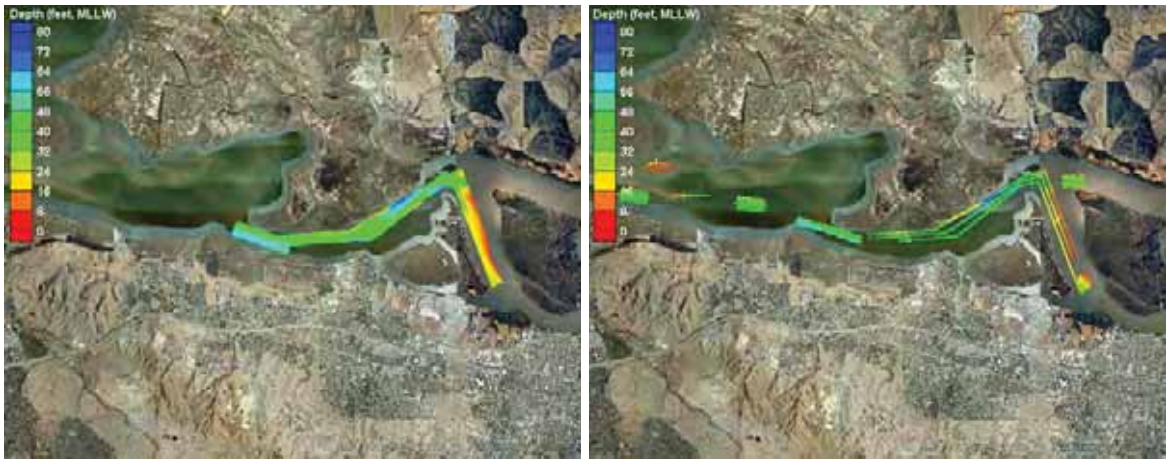

Figure 4-3. Suisun Bay depths from USGS multi-beam bathymetry data set, 2007 (various dates, left) and from E-Trac single-beam data set, 2008 (various dates, right)

With the exception of Middle Ground (TLS39), the volume changes over time in each lease area and most of the reference sites are without a clear pattern. The only other observed long-term trend was sediment depletion in control site 2, apparently due to general deepening occurring at this location (which is at the confluence of the Sacramento and San Joaquin Rivers).

The other control sites do not have a long-term depletion trend; however, all areas downstream of the Sacramento River, including East and West Suisun Associates, but excluding Middle Ground, showed noticeable depletion following the December 2005/January 2006 flood event (see Figure 4-4 for control site 2 as an example). The Middle Ground lease area did not experience erosion following this flood event likely because it contains relatively large depths that have been artificially deepened relative to the surrounding areas.

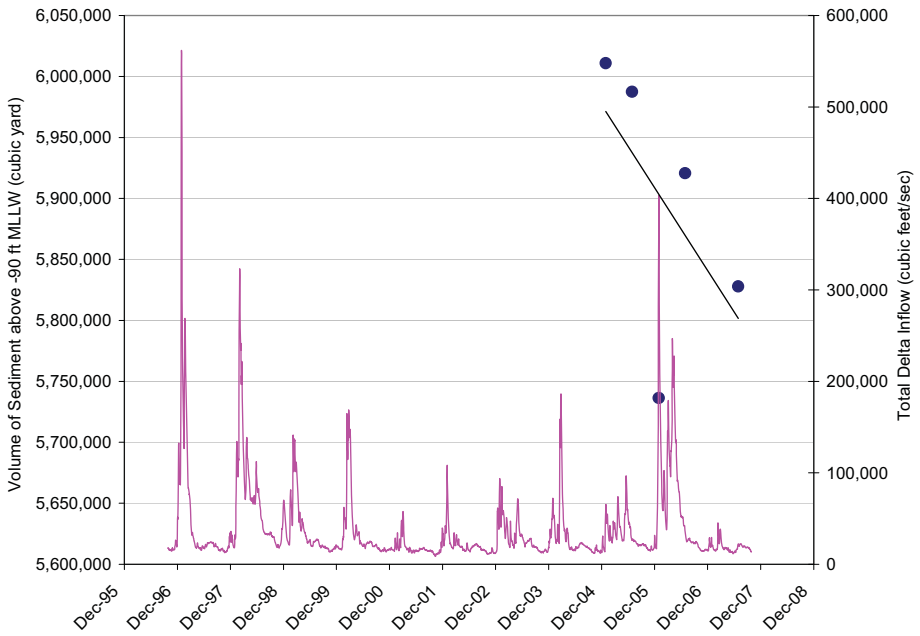

Figure 4-4. Volume of available sediment above -90 ft MLLW and below -3 ft MLLW for Control Site 2 and total delta inflow (DAYFLOW model)

The observed net erosion in the control sites (which are in deeper areas near the channel centerline) immediately following the December 2005/January 2006 flood event appear to indicate that large river flows moving through the area tend to erode more sand/sediment from the main channel areas of Suisun Bay than they deliver. This finding is consistent with recent low maintenance dredging volumes reported by the U.S. Army Corps of Engineers (Bay Conservation and Development Commission, personal communication 2008). Given the apparent net erosion in the control sites following this flood event, it seems likely that sedimentation in the lease areas and navigation channels in recent years is mostly a result of local sediment transport, and that net transport through the area is small except during large flood events. Bathymetry change analysis in Suisun Bay indicates the following:

- Considering that a recent large flood event caused erosion rather than accretion in the reference sites, it appears that the material that was mined during this period had been mostly deposited from surrounding areas.
- Bottom changes in the reference sites and outside the lease areas were generally small from survey to survey (with the exception of control site 2), likely due to the large size of the surrounding areas that are contributing sediment to the deepened lease areas.
- Continuation of sand mining in Suisun Bay during the proposed 10-year period is not likely to cause measurable sediment depletion in areas outside the mining areas, such as the reference sites and areas in San Pablo/Central Bay.

- Since the material entering the lease areas appears to be finite and mostly from the surrounding areas, analysis should be performed prior to subsequent lease renewal periods.

4.2. Sand Mining Impact Evaluation from Numerical Modeling Tools

4.2.1. Modeling and Analysis Approach

The goal of the numerical modeling analysis was to provide an additional methodology for evaluation of potential impacts of sand mining on hydrodynamics, sediment transport, and salinity within San Francisco Bay on a short-term and longer-term basis. San Francisco Bay hydrodynamics are the primary driving force behind water quality and sediment transport/morphology. Therefore, the primary analysis effort and conclusions from the modeling results were made based on hydrodynamic modeling of tidal and river flows.

In order to develop more confidence in the hydrodynamic modeling results and choose the most appropriate tool for impact evaluation, four different well-respected numerical hydrodynamic modeling codes were applied to evaluate San Francisco Bay existing hydrodynamic conditions:

- SELFE (Zhang *et al.*, 2005). The model includes 3D simulation of flows, water levels, salinity and temperature.
- FVCOM (Chen *et al.*, 2006). The model includes 3D simulation of flows, water levels, salinity and temperature.
- ADCIRC2D (Luettich *et al.*, 1992). The model includes 2D simulation of flows and water levels.
- MORHPO-UNS (Kivva *et al.*, 2006). The model includes 2D simulation of flows and water levels.

The two main objectives of initially testing these four different hydrodynamic modeling tools were the following:

- Determine if differences existed between results from the modeling tools, and hence capture a more conservative, full range of potential impact results.
- Finalize which hydrodynamic tool to use for full-year hydrodynamic and sediment transport analysis.

Identical simulations were performed for all four model codes and the results of all codes are compared in Appendix D. The modeling tools were shown to generate similar results. The SELFE model was chosen for short-term and full-year impact analysis due to good validation results, efficient simulation of long time periods and inclusion of 3D flows with salinity. Appendix D describes the SELFE tidal hydrodynamic model development and validation. Figures 4-5 and 4-6 show color representations of the modeling domain.

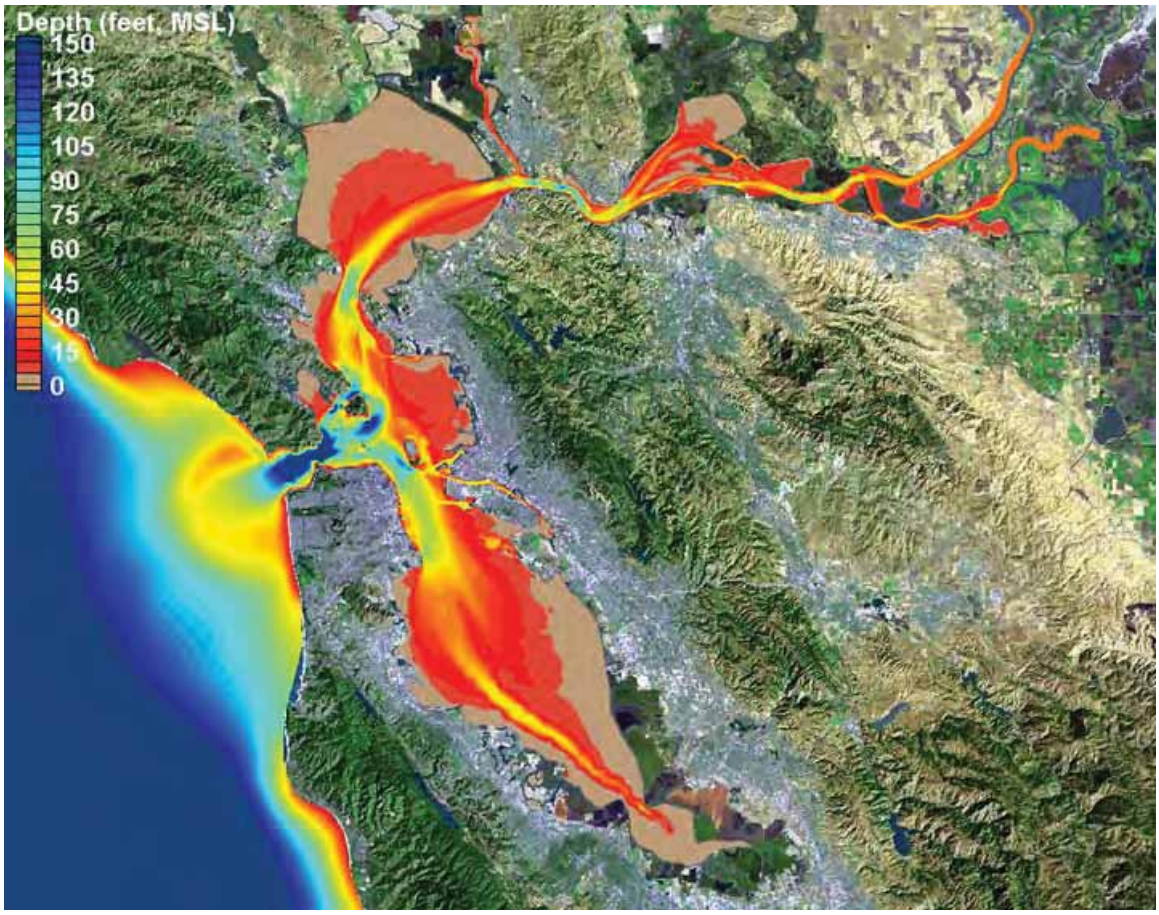

Figure 4-5. San Francisco Bay modeling domain coverage (areas inside the Bay shown) and water depths

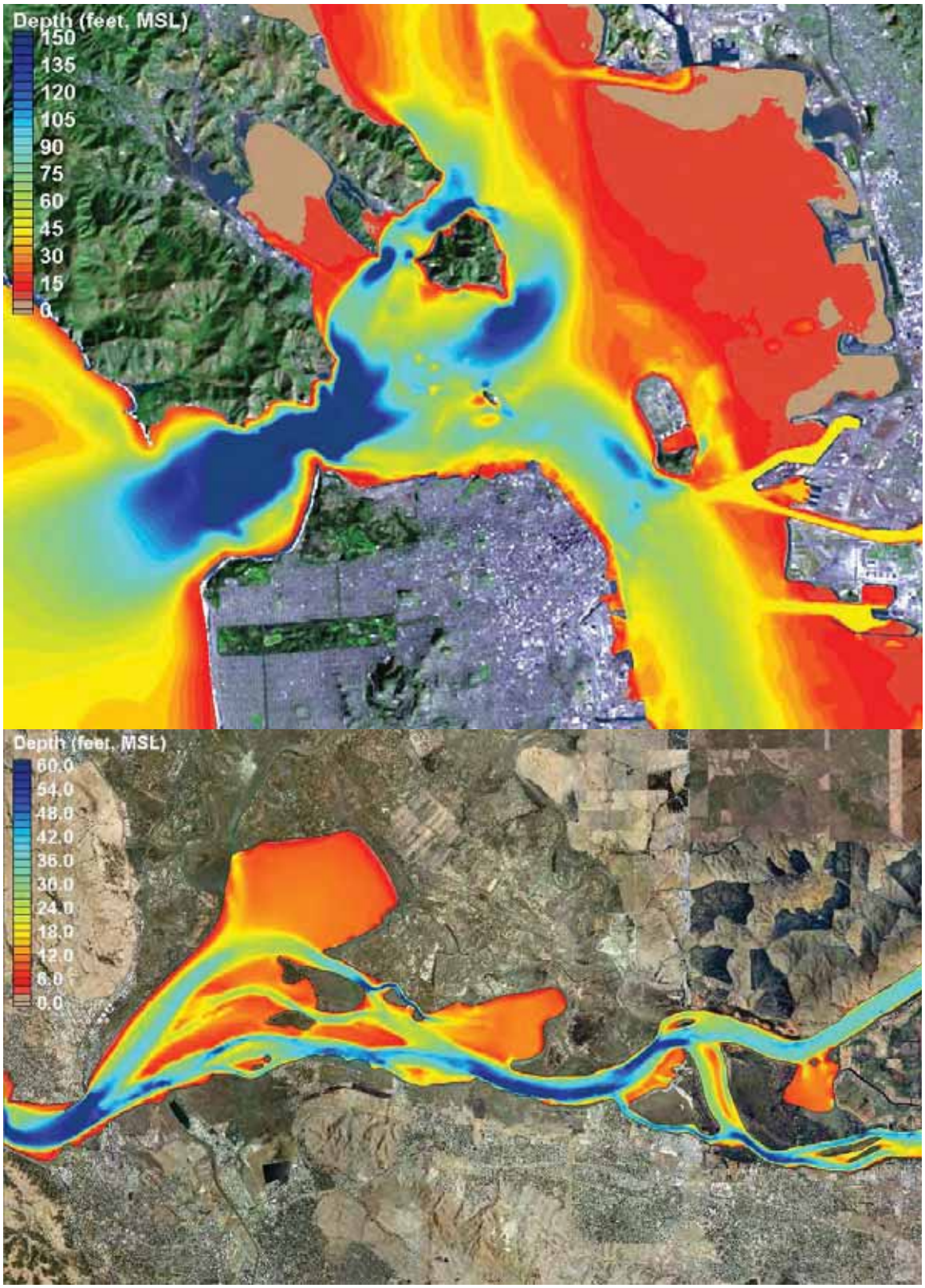

Figure 4-6. Modeling domain close-up in Central Bay (top) and Suisun Bay (bottom)

4.2.2. Modeling Scenarios

Circulation, sediment transport, and salinity were simulated for existing conditions and the following two mining scenarios developed in coordination with ESA and CSLC and approved by CSLC prior to analysis:

1. Scenario 1: 10 yrs of mining occurs all at once, covering the entire lease areas with a constant dredging thickness (Figure 4-7).
2. Scenario 2: 10 yrs of mining occurs all at once, with coverage determined from worm tracks from past mining events, using a constant dredging thickness. Dredging coverage was determined to be approximately 25% of the lease areas, on average (Figure 4-8). The lease areas were dredged only over areas consistent with the relevant sand mining regulatory permits.

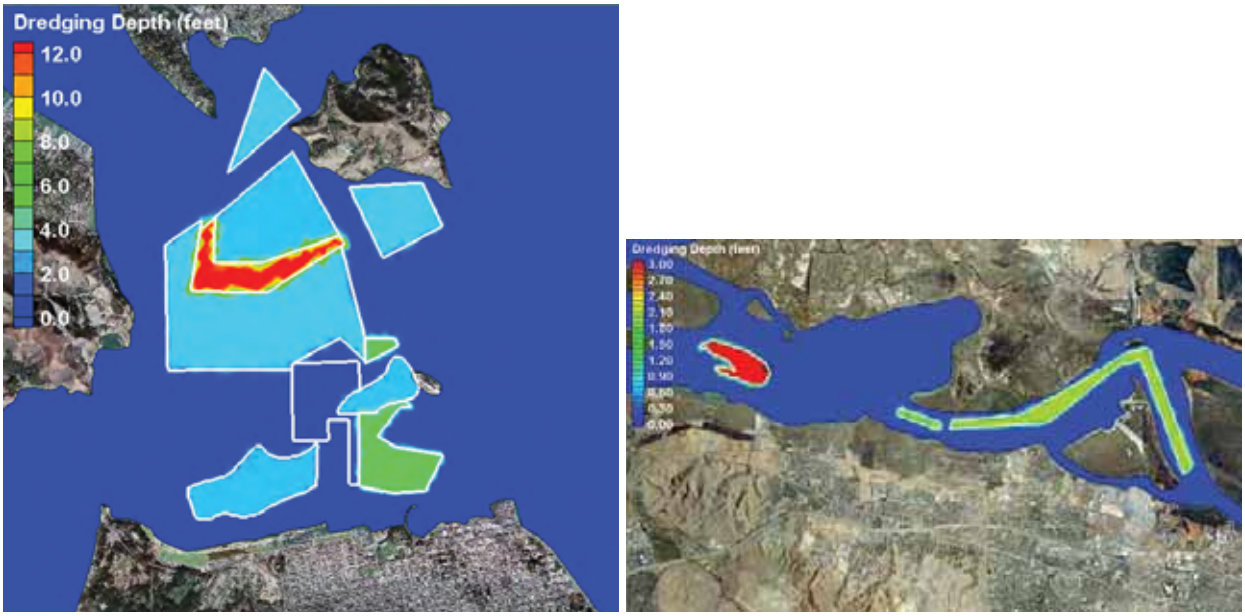

Figure 4-7. Sand mining depth changes for Scenario 1 for Central Bay (left) and Suisun Bay (right)

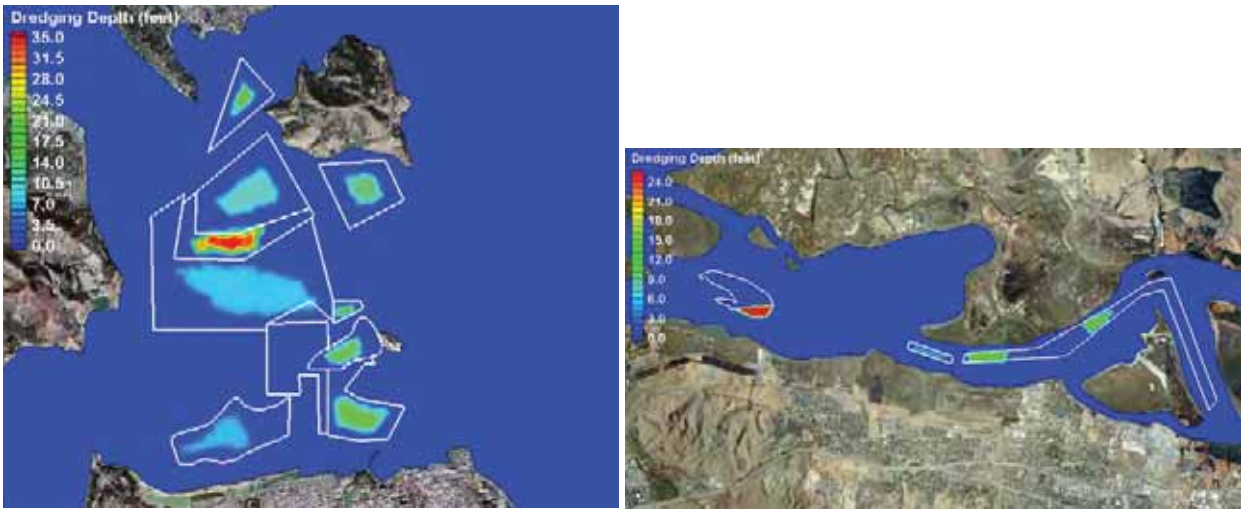

Figure 4-8. Sand mining depth changes for Scenario 2 for Central Bay (left) and Suisun Bay (right)

4.2.3. Simulation Conditions/Periods

Modeling simulations were conducted for 15-day periods (short-term runs), and full-year periods. The full-year modeling simulations were intended to span all types of potential hydrodynamic conditions, including both weak and strong river flows. The December 1, 1996 to December 1, 1997 period was used for modeling because analysis of historical records indicated that this time period contained physical processes with and without large river flow effects. Appendix D describes the river flow and initial salinity/temperature conditions used in the model.

Potential impact analysis was performed for two types of simulations: short-term (15 days) and full-year. The short-term simulations focused on details of strong tidal flows with low river flows (early December 1996). The full-year simulations focused on tidally averaged flows and longer-term analysis, including extreme flows that occurred in December 1996 and January 1997.

Two different analysis methods were used to determine short-term hydrodynamic changes from sand mining: 1) plan view differences in mid-depth velocities during typical peak ebb and flood currents; and 2) time series analysis of mid-depth velocities at selected points surrounding the lease areas (see Figures 4-9 and 4-10).

Figure 4-9. Locations of time history extraction points in Central Bay

Figure 4-10. Locations of time history extraction points in Suisun Bay

4.2.4. Changes in Circulation due to Sand Mining

Figure 4-11 shows typical peak flood (top) and ebb (bottom) mid-depth velocities for existing conditions from the SELFE model for Central Bay.

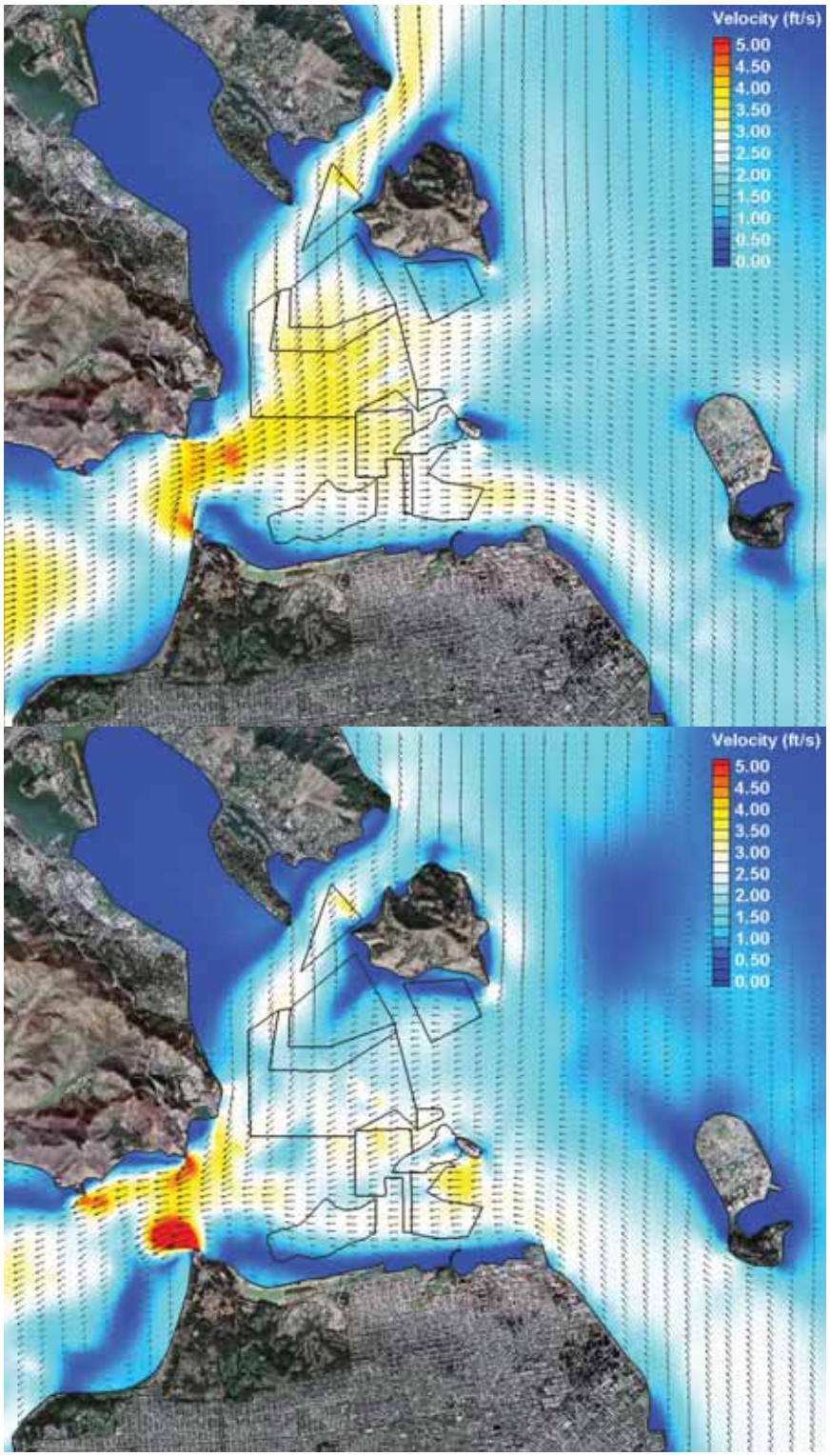

Figure 4-11. Typical flood (top) and ebb (bottom) mid-depth velocities for existing conditions

In order to detect changes in velocities, current speed difference maps were prepared. Figures 4-12 and 4-13 shows mid-depth current speed differences caused by Scenario 1 and Scenario 2, respectively, as compared to existing conditions. Analysis indicates that in general the velocity patterns surrounding the lease areas are very similar between Scenarios 1 and 2 compared to existing conditions, with only small velocity changes noticeable in the immediate vicinity of the lease areas.

Changes in mid-depth current speeds are less than approximately 1.0 feet/sec, even when measured over the most heavily mined lease areas. Changes are generally not measurable at mid-depth for distances away from the lease areas that are as large as the lease areas themselves.

It should be noted that comparison of existing conditions and after-mining conditions by direct velocity subtraction at the exact same moment in time is a highly conservative analysis approach, because introduction of project features has been known to cause small shifts in the timing of peak velocities. This produces changes in plan view that are not significant in a time history of velocity from a specific location.

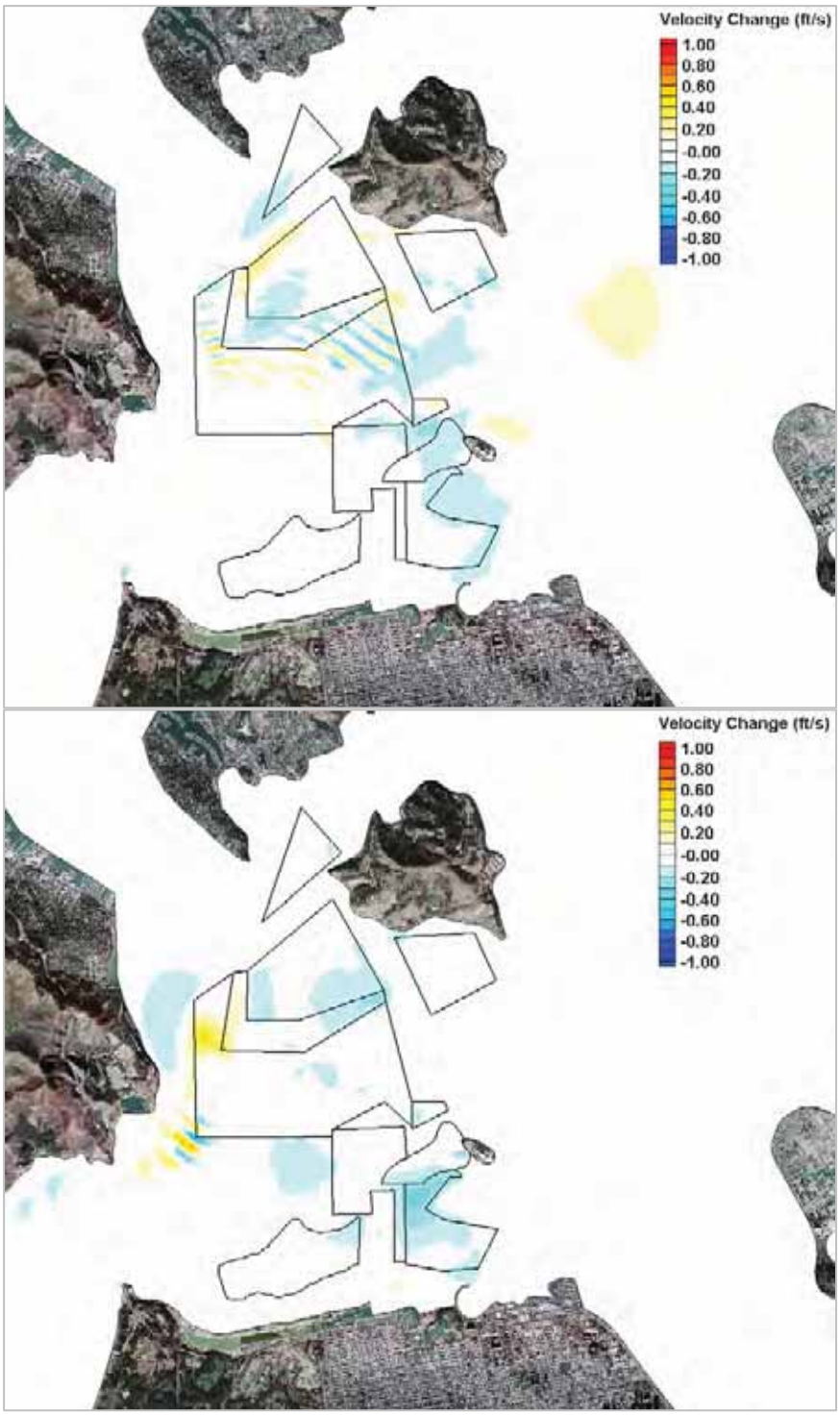

Figure 4-12. Mid-depth flood (top) and ebb (bottom) current speed differences caused by Scenario 1

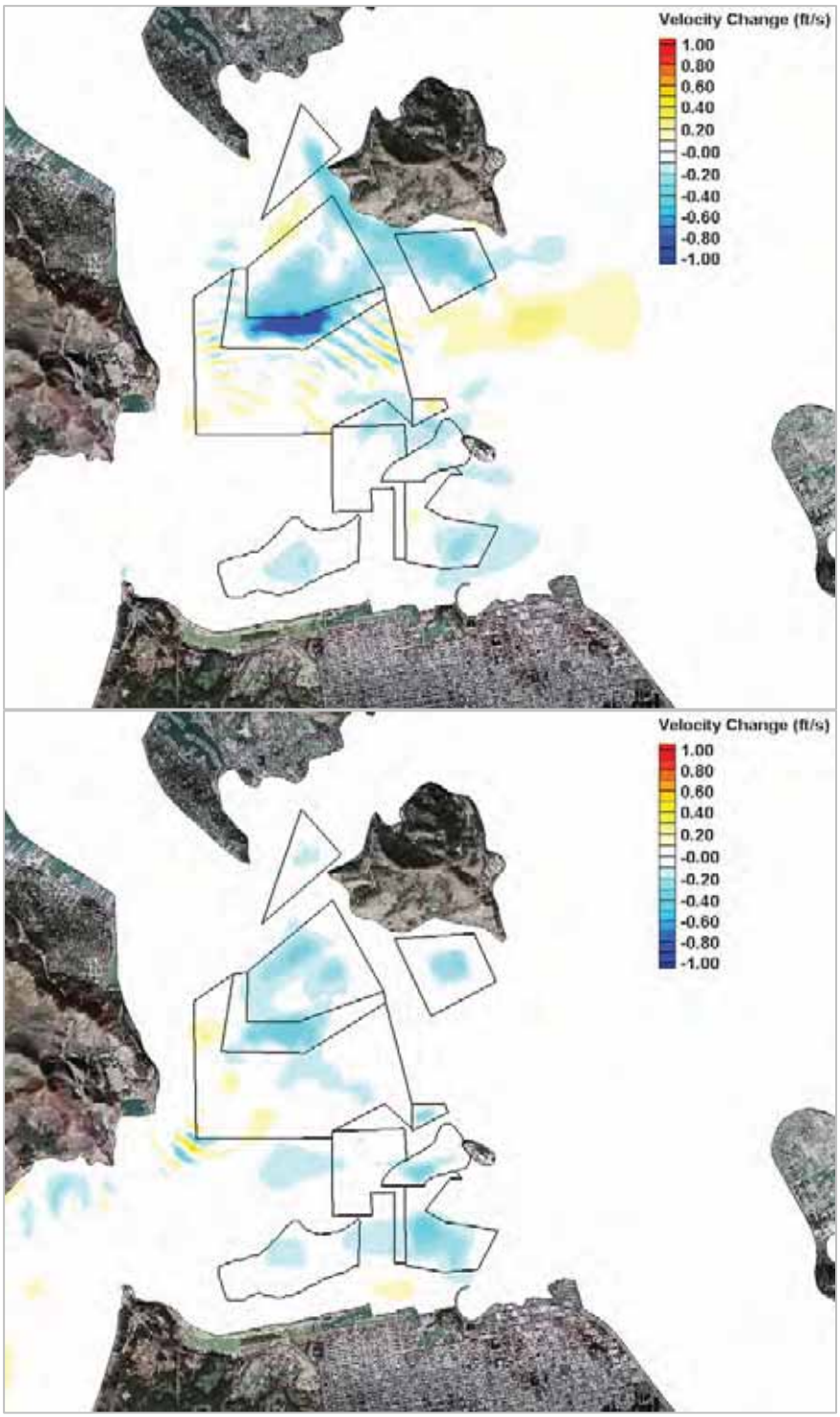

Figure 4-13. Mid-depth flood (top) and ebb (bottom) current speed differences caused by Scenario 2

A time series analysis of mid-depth velocities surrounding the lease areas was also performed at Points 1 - 21 shown in Figures 4-9. Figure 4-14 shows time histories of mid-depth velocity at Points 4 (left) and 10 (right) in Central Bay. The velocity time histories for Scenario 1 and Scenario 2 for existing conditions are not distinguishable

in the figure, indicating that bathymetry changes due to sand mining do not measurably change the overall current speed regime at these locations. The maximum current speed difference present at any Central Bay analysis location (see Figure 4-9) for both alternatives was approximately 0.05 feet/sec. In general, the current speed differences caused by the sand mining at the locations used for analysis are not expected to be measurable.

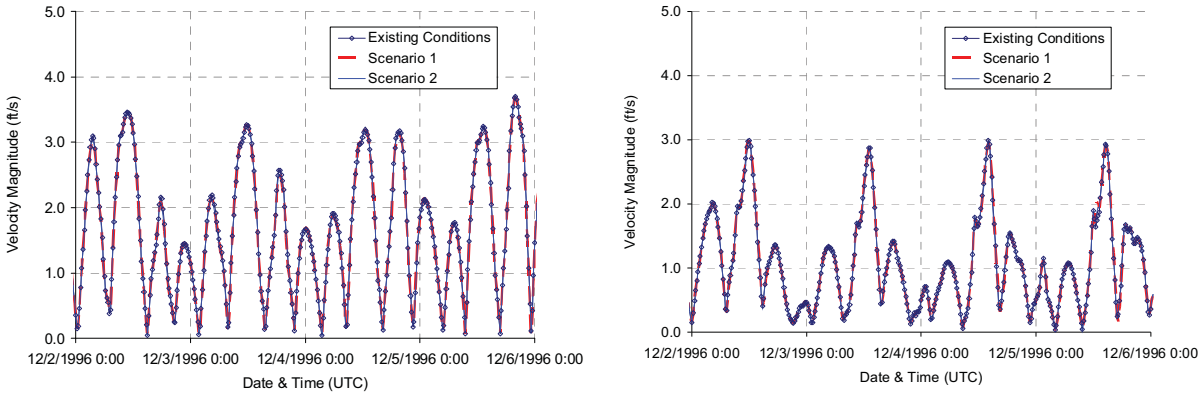

Figure 4-14. Mid-depth current speed at Point 4 (left) and Point 10 (right) for existing conditions, Scenario 1 and Scenario 2 (point locations in Figure 4-11)

Full-year simulations were performed with the SELFE model using hydrologic and tide data forcing from the period between December 1996 and December 1997. Existing conditions, Scenario 1 and Scenario 2 were simulated and hydrodynamic statistics, net values, and averages were developed to represent the longer-term conditions for each alternative. Potential impacts of sand mining were primarily evaluated using changes in net (tidally averaged) current velocities. Appropriate averaging periods were determined through sensitivity analysis.

Figure 4-15 shows the one-year net (long-term average) flows for existing conditions in Central Bay. Figure 4-16 shows the changes in net flows induced by Scenarios 1 and 2 (top and bottom, respectively). The color contours represent changes in net flow magnitudes and the vectors represent the net flows for existing conditions. As with short-term hydrodynamics, the full-year net flows in Central Bay are not measurably affected in areas outside the immediate vicinity of the lease areas.

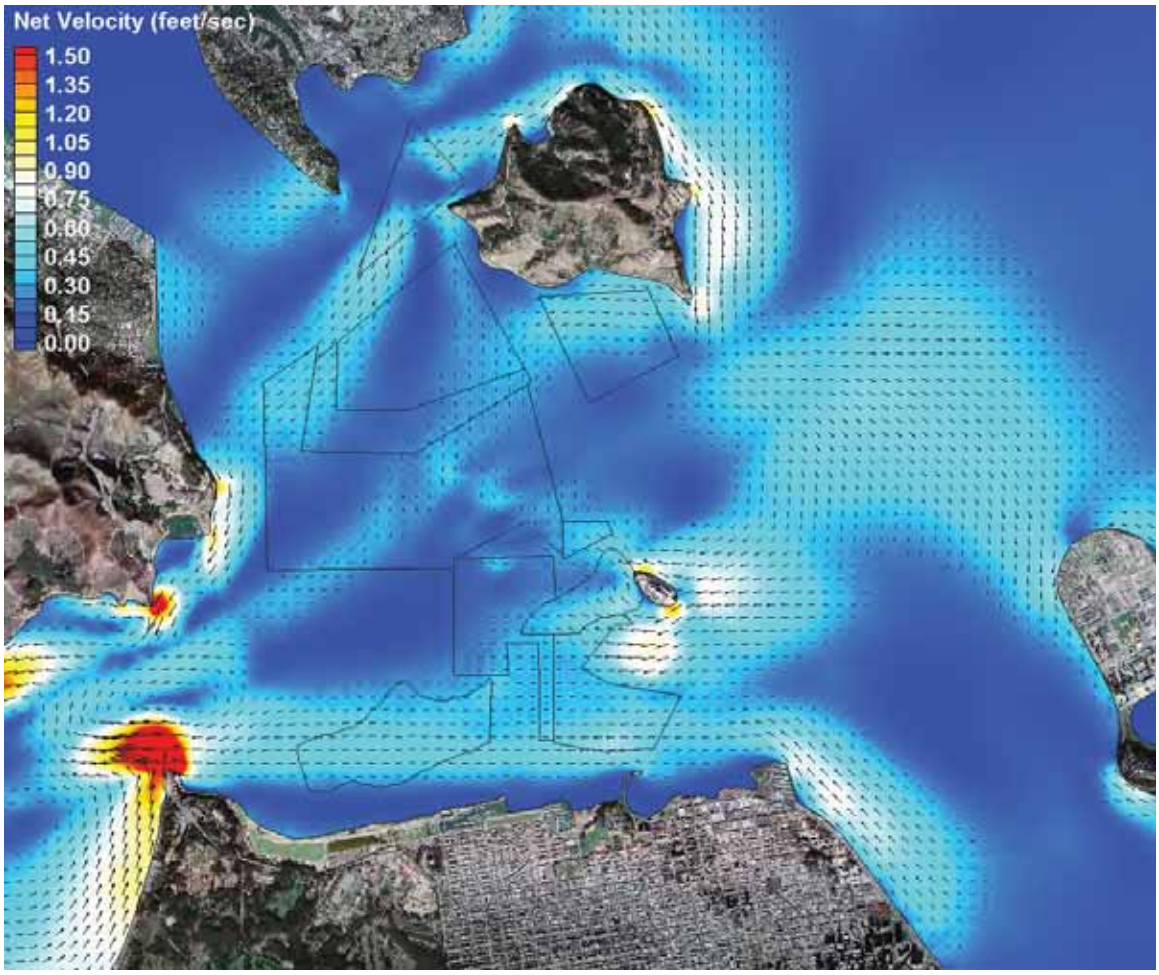

Figure 4-15. Net current velocities (December 1996 to December 1997) in Central Bay for existing conditions