PORT OF OAKLAND
Outer Harbor Maintenance Dredging Operations

Spatial Characterization of Suspended Sediment Plumes During Dredging Operations Through Acoustic Monitoring

Final Report

Prepared For:

U.S. Army Corps of Engineers, San Francisco District
333 Market Street
San Francisco, California 94015-2197

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January 7, 2004

TABLE OF CONTENTS

LIST OF FIGURES

(Bold indicates maps that reference locations of transect profile figures)

Introduction

The ability to discern spatial and temporal characteristics of suspended sediment plumes, including their concentration gradient structure, is an important tool in documenting any potential impact dredging and dredge material disposal projects may have on sensitive aquatic species and associated habitat. Acoustic Doppler Current Profiler (ADCP) technology has been employed in recent studies to identify suspended sediment plumes by correlating the acoustic return signal (backscatter) to total suspended solids (TSS) in the water column. This project utilizes ADCP technology to track plumes during bucket dredging operations in the Port of Oakland's Outer Harbor.

Project Location

Plumes were characterized during maintenance dredging operations in the Outer Harbor of the Port of Oakland. The dredging operations were located off the southeast corner of Terminal 7 (Figure 1). The long axis of the navigation channel along this pier is oriented southwest to northeast with a dogleg to the east further inside the harbor. The harbor "dead-ends" inside of this dogleg, with no source of freshwater at its terminus. For the purpose of this report, any reference to the "inner harbor" refers to the closed basin area around Terminal 20 of the Outer Harbor, and not to the Inner Harbor channel of the Port of Oakland, located approximately 1.5 miles to the south of Outer Harbor.

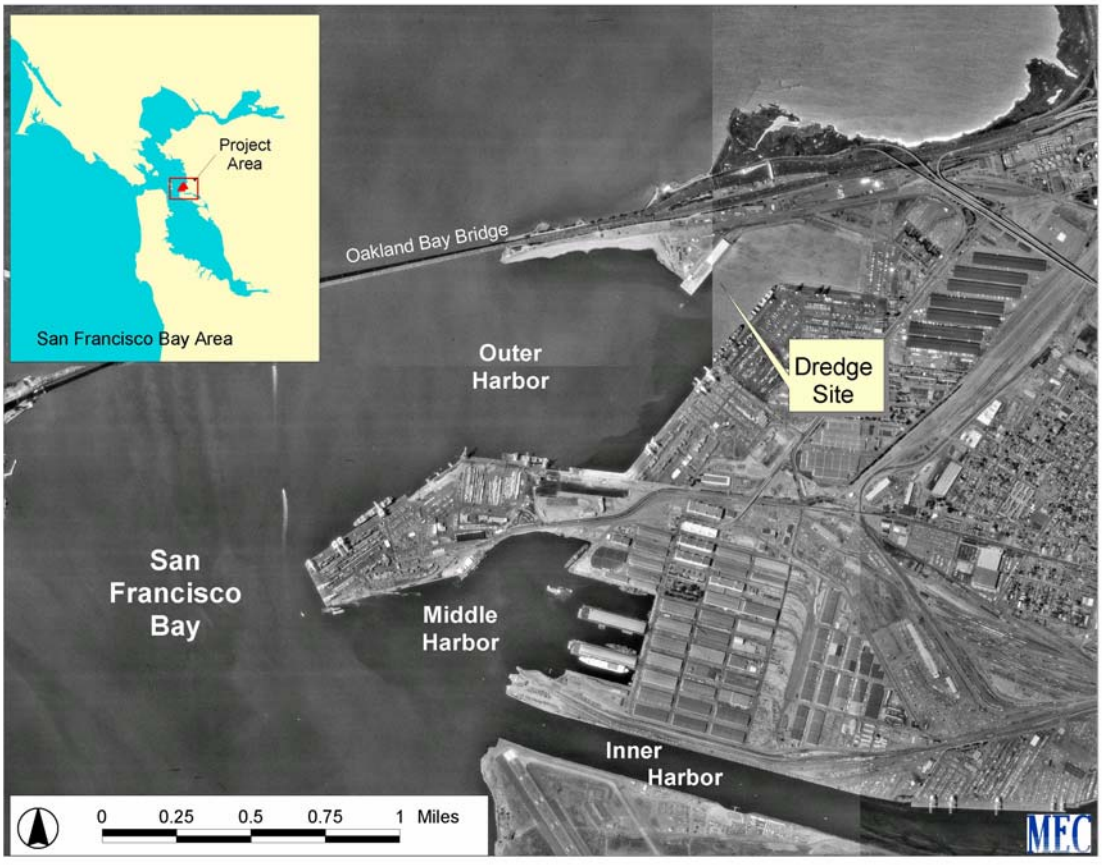

Figure 1. Port of Oakland and Project Site Location Map.

Methods

Surveys of suspended sediment plumes began on August 26, 2003 and continued through August 27, 2003. On August 28, 2003 operations ceased to allow for maintenance of the dredge. The following day, August 29, 2003, operations were suspended, as directed by the United States Army Corps of Engineers Project Manager for the Port of Oakland, to relocate the dredge and dump scow for emergency maintenance operations in the Turning Basin. Background (ambient conditions) data were collected during an initial mobilization effort on August 20, 2003 and on August 28, 2003, during the period when the dredge had become inactive.

Multiple surveys were performed during dredging operations on flood and ebb tide cycles, as well as during stoppages to collect ambient condition data. Transects were initially established in parallel orientation with 100-meter spacing up-current and down-current of the dump scow. Surveys were conducted once dredging operations had been underway for a sufficient amount of time for a plume to fully develop. The 100-meter transect spacing was maintained when a plume signature was not evident in the real time data plots; however, to obtain optimal resolution of plume structure, transect spacing was shortened in close proximity to the barge and when a plume signature was clearly defined.

Monitoring of the dredge plume was conducted from a 44-foot welded aluminum survey vessel, the RV Zephyr. The vessel was equipped with a stern-mounted A-frame for deployment of water quality instrumentation. A Garmin 54 differential global positioning system (DGPS) was used to provide navigation and position data. The vessel's recorded position was therefore known to an accuracy within ±3 meters. The DGPS signal was split and used by the vessel Captain in Nobletec's NavTrek software and by the survey crew to provide position data in RD Instrument's ADCP data collection software, WinRiver.

Acoustic monitoring of the suspended sediment plumes was performed with an RD Instruments 600-kHz Sentinel Workhorse ADCP. The ADCP was side-mounted midships, with the transducer head 0.75 meters below the surface of the water (Figure 2). The ADCP was used to collect current velocity, direction, and acoustic backscatter data. RD Instruments WinRiver software running on a laptop computer was used to display and record these data. The instrumentation package calculated and recorded vessel and current direction in three-directional axes to an accuracy of ±0.2 cm/sec. Data were recorded for predetermined horizontal and vertical bins (vertical bin size = 0.15m). Bottom depth and surface water temperatures were also recorded. An internal fluxgate compass allowed the instrument to correct ADCP current vectors for vessel speed and orientation. Navigation data received from a differential Global Positioning System were collected synoptically and integrated during post-processing.

ADCP acoustic backscatter data were analyzed using Sediview Software provided by Dredging Research Ltd. The Sediview Method (Land and Bray 2000) derived estimates of TSS concentration in each ADCP data bin by converting relative backscatter intensity to TSS concentration. This process required collection of a field data set consisting of discrete water samples analyzed gravimetrically. The sample population represented the concentration gradient prevailing at the study site, and was used to "groundtruth" the acoustic data. The calibration samples were collected at known locations within the insonified portion of the water column, so that individual gravimetric samples could be directly compared with acoustic estimates of TSS concentration for the same unit volume of water. An example of the acoustic methodologies for plume characterization can be found in Reine et al. (2002).

Figure 2. Side mounting location of ADCP.

For calibration of the acoustic backscatter data to TSS concentration, water samples for total suspended solids (TSS) analysis were collected utilizing a rosette sampler consisting of 9 Niskin water samplers (Figure 3). The Niskin bottles were manually triggered to close, typically at 1-meter depth intervals and dependent on the observed backscatter signal from the ADCP. Integrated with the rosette sampler was a Seabird Electronics instrumentation package that continuously recorded water quality measurements of depth, salinity, temperature, conductivity and transmissivity. The TSS samples were sent to MEC's laboratory in Tiburon, California, for gravimetric analysis.

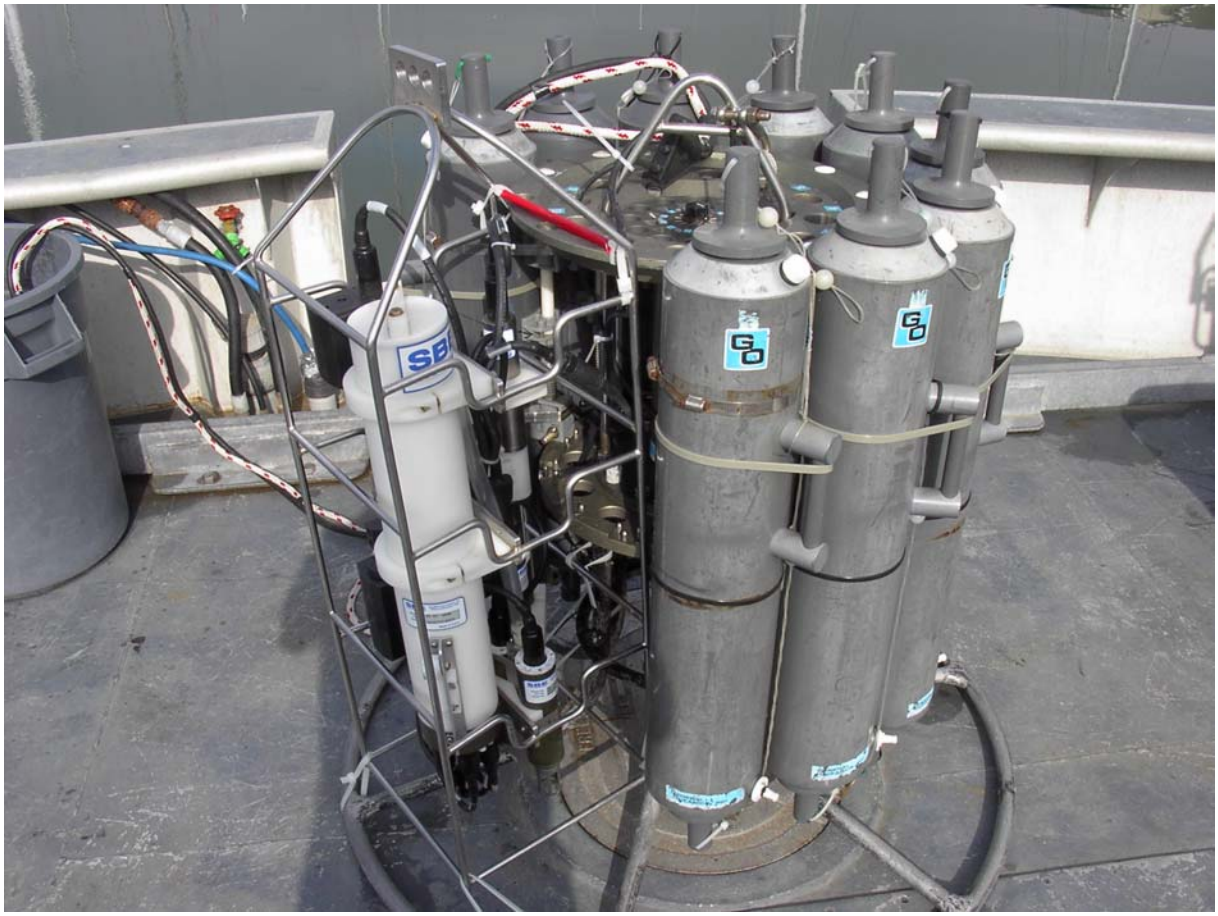

Figure 3. Rosette sampler.

Dredging was conducted with a 12-cubic yard closed cable bucket operated by the Dutra Group. Dredging operations were punctuated by frequent stoppages for routine maintenance, repositioning of the dredge, or replacement of full dump scows with empty scows.

Results

File names utilized during the field operations of this project are referenced throughout this report. These are intended as label reference only, indicating the tide stage and survey name. Within these file names, the second to last character indicates whether the survey was conducted during an Ebb (E) or Flood (F) tide and the last character indicates the order in which surveys were taken (first, second, etc.). For example, ODEA indicates the survey was the first (A) conducted during an ebbing (E) tide.

Acoustic TSS Concentration Data Calibration

The acoustic backscatter to TSS concentration calibration data set consisted of a total of 55 water samples. In Figure 4, the populations of gravimetric and acoustic TSS concentration measurements are compared. For data collected at Outer Oakland Harbor the relationship between gravimetric and acoustic measures had a relatively high degree of correspondence, with acoustic TSS concentrations tending to be slightly higher than gravimetric TSS concentrations in the 0 to 90 mg/l range, and slightly lower than gravimetric TSS concentrations in the 90 to 400 mg/l range. Appendix A provides a summary of the analytical results for TSS.

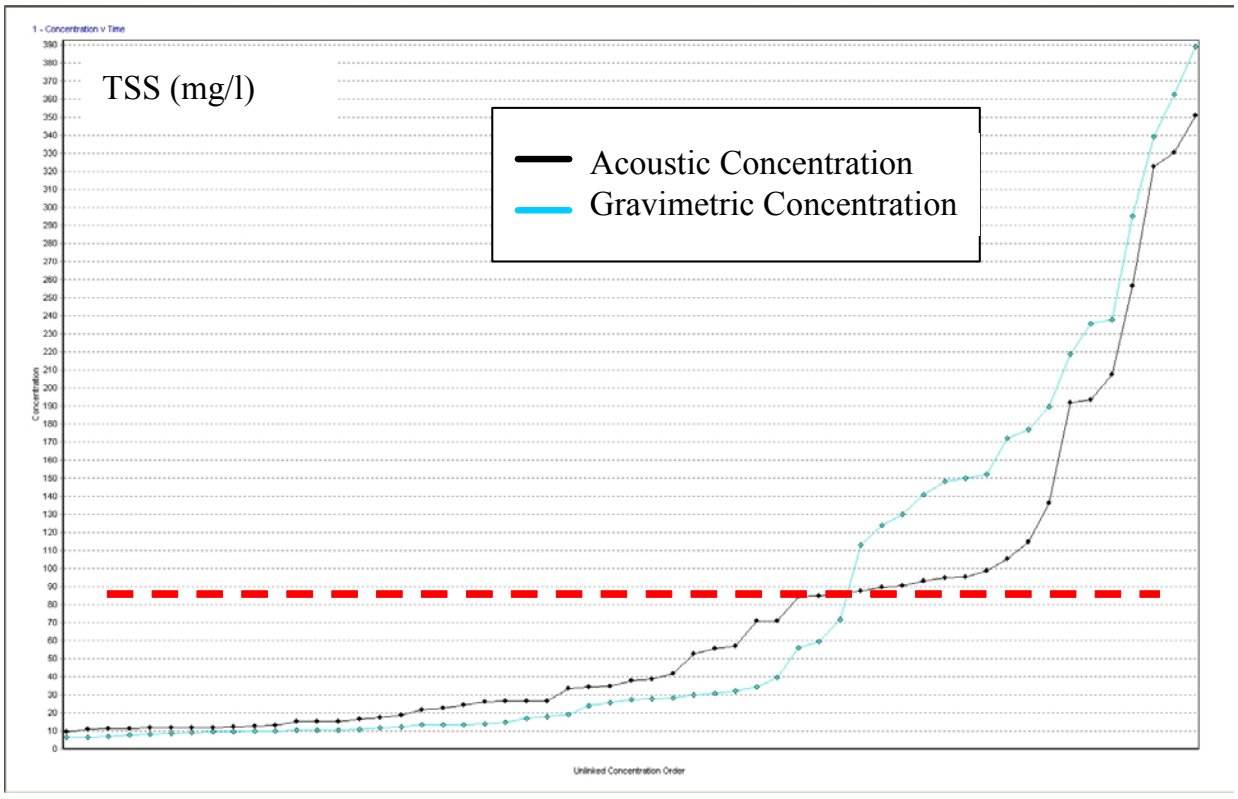

Figure 4. Comparison of acoustic and gravimetric measurements of TSS concentration in rank order. Dotted line indicates the concentration (~ 90 mg/l) that separates the low range in which Sediview tends to slightly overestimate concentration, and the high range in which Sediview tends to slightly underestimate concentration.

Ebb Tide Current Structure

Depth-averaged current vectors for an ADCP survey of an ebbing tide are depicted in Figure 5. Vector headings were randomly scattered, indicating a lack of uniform flows. Inspection of the data for structured flows in either surface or bottom portions of the water column did not reveal departures from this random pattern. Current velocities were relatively slow throughout the study area, generally less than 25 cm/sec. No indication of increasing or decreasing flows was seen as the survey progressed through the early to late stages of the tide. The lack of strong flows contributed to the apparent randomness of the directional vectors, as the ADCP has difficulty resolving direction at such slow velocities (RDI 2003).

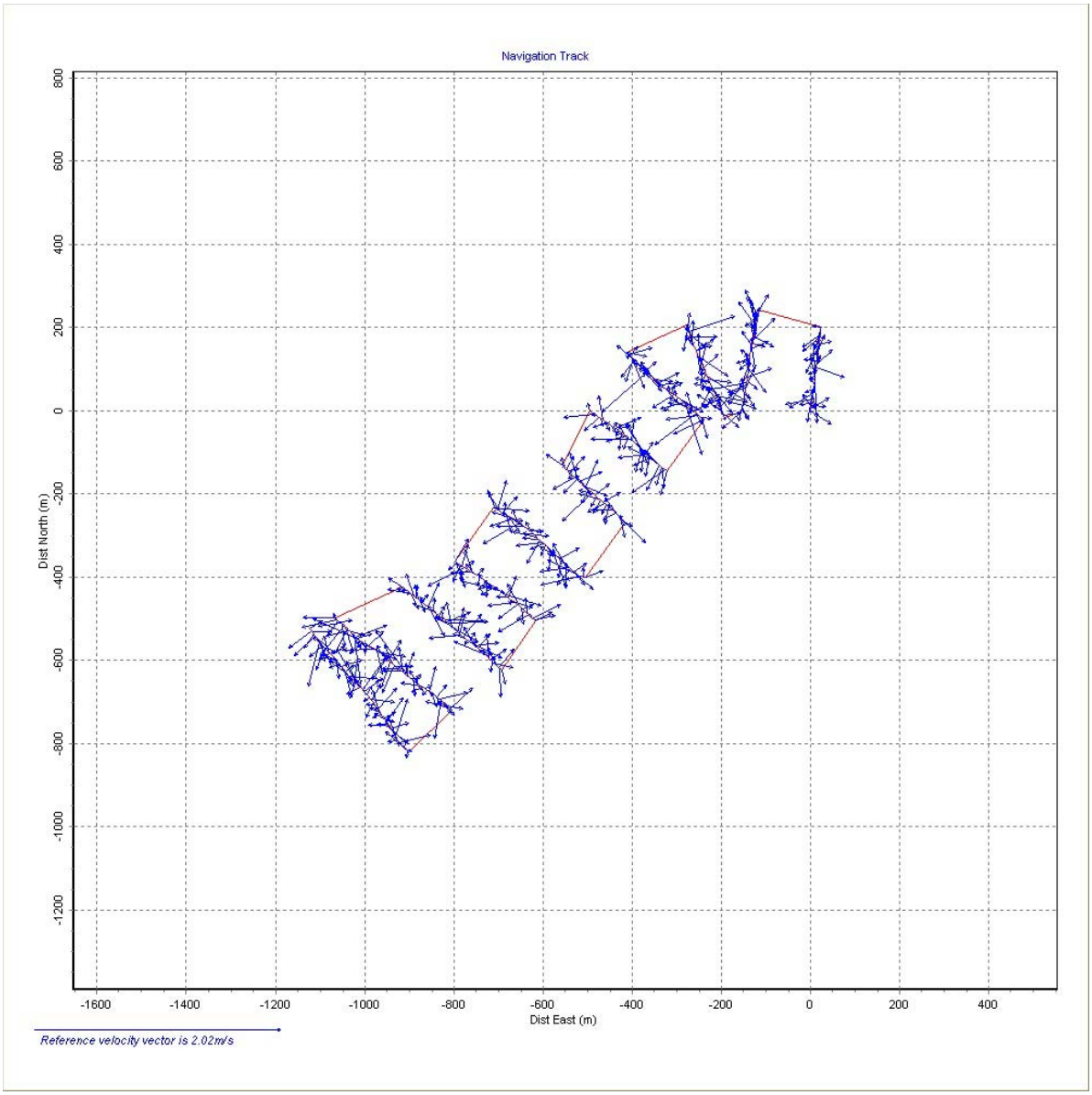

Figure 5. Depth-averaged directional current vectors across ADCP survey ODEA transects during an ebbing tide in Outer Oakland Harbor.

Flood Tide Current Structure

Depth-averaged current vectors for an ADCP survey (ODEA) of an ebbing tide are depicted in Figure 6. Similar to currents observed during ebbing tides, the vectors show no general pattern in terms of directional flows, as evidenced by the rather random scattering of vector headings both along individual transects and between transects. All flood flow velocities were relatively slow, but somewhat higher than observed in the ebb surveys. Flood flow velocities were generally less than 40 cm/sec. The measured currents were consistent throughout the water column; there were no observed differences in surface or bottom waters. These data were consistent with flows measured in all of the surveys conducted, both during ebb and flood tidal stages.

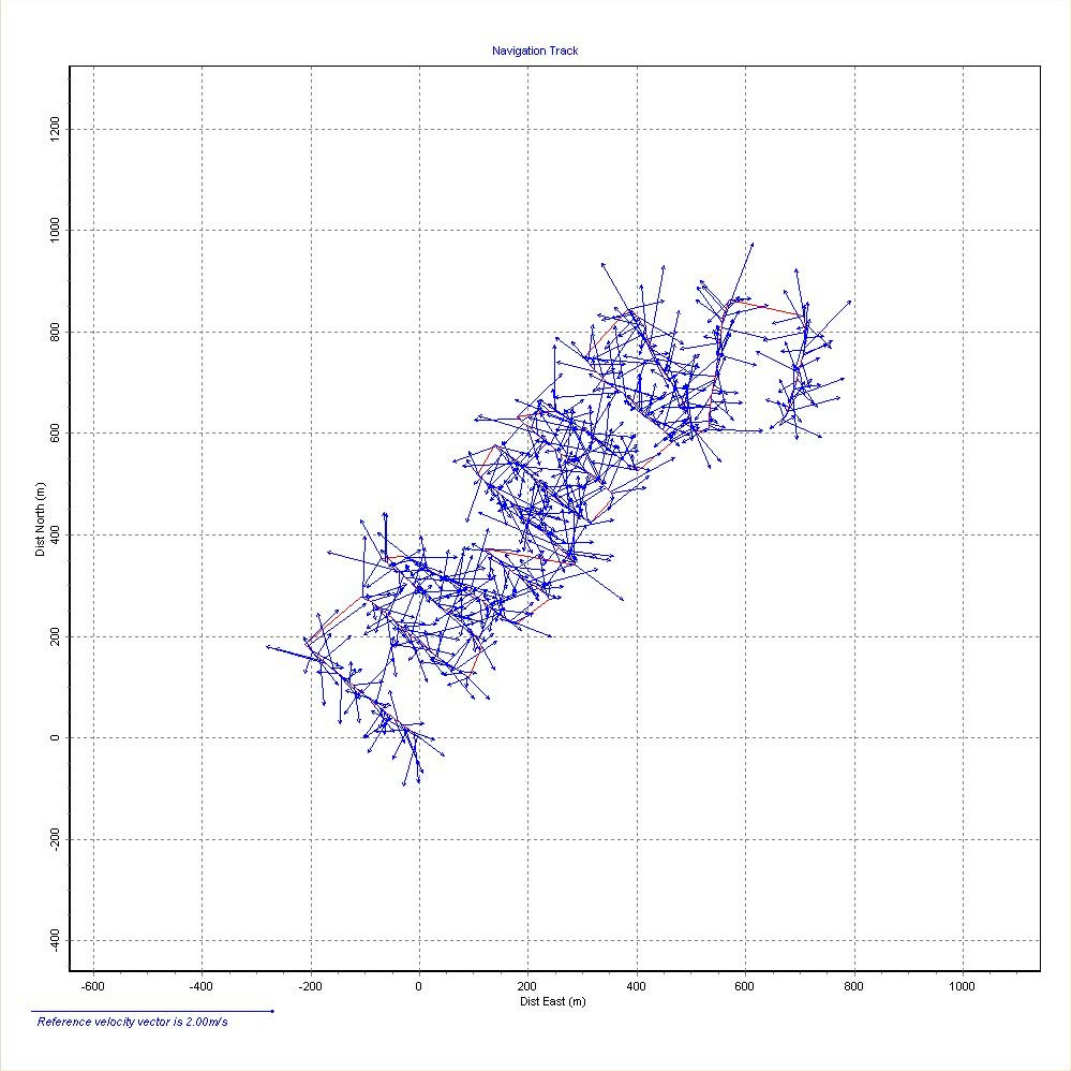

Figure 6. Depth-averaged directional current vectors across ADCP survey ODFC transects during a flooding tide in Outer Oakland Harbor.

Ambient Conditions Characterizations

Due to unanticipated changes in the mobilization dates of the dredging project, no opportunity was available to conduct an ADCP survey in the absence of a dredge. However, general ranges of ambient TSS concentrations was estimated on the basis of data collected outside the area

influenced by plumes, and from a survey conducted before the dredge attained full production mode. References to TSS concentrations outside of plumes are made at appropriate places in the text. The first full ADCP survey (ODEA) was completed during a period of little dredging activity, and can be examined for an approximation of ambient conditions. This survey was conducted during an ebbing tide stage. A plan-view layout of the Outer Oakland Harbor study area with locations of the survey transects is given in Figure 7. The survey consisted of 11 transects established in roughly parallel orientation at approximately 100m intervals perpendicular to the long axis of the navigation channel. Each transect extended across the entire channel cross-section within the 3 m depth contours. This basic survey design was followed in all ensuing ADCP surveys, with adjustments of the transect widths where necessary to accommodate locations of the dredge, tenders, and barges. Transects have been enumerated in series beginning with Transect 1 at the bay-ward extremity of the survey area to Transect 11 at the innermost section of the harbor.

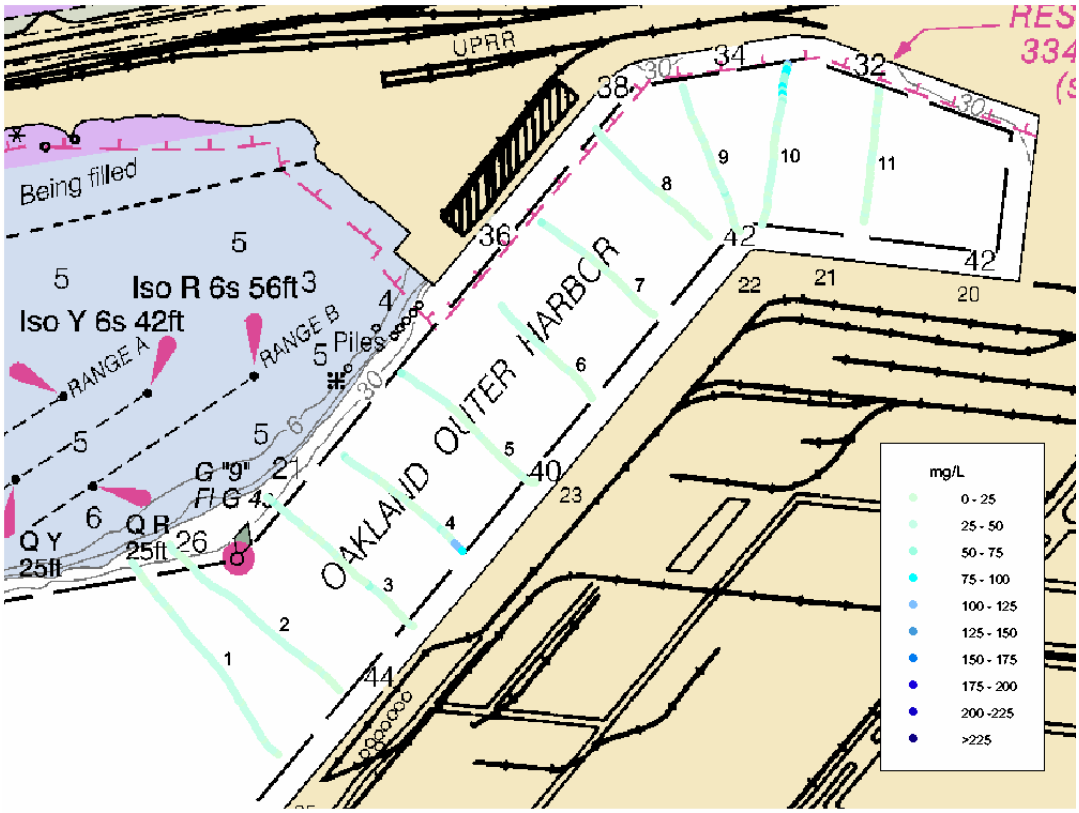

Figure 7. Locations of ADCP Survey ODEA transects in Outer Oakland Harbor during an ebbing tide. Depth-averaged acoustic estimates of TSS concentrations prevalent during a period of relative dredging inactivity.

As can be seen in Figure 7, ambient TSS concentrations were generally below 50 mg/l throughout the study area with the exceptions of small parcels of elevated TSS concentration at ends of Transects 4 and 10. These occurrences of high TSS concentration may have been linked to the onset of a dredging plume, or to the passage of commercial ship traffic through the harbor.

The vertical structure of non-depth-averaged ambient TSS concentrations are presented for Transects 1, 5, and 10 in Figures 8, 9, and 10, respectively. On Transect 1, closest to open bay waters, a distinct increase in TSS concentration with increasing depth was apparent. Total

suspended sediment concentrations as high as 100 mg/l were found in the deep, central-channel bottom waters. Total suspended sediment concentrations in surface waters above 8 m were generally below 25 mg/l.

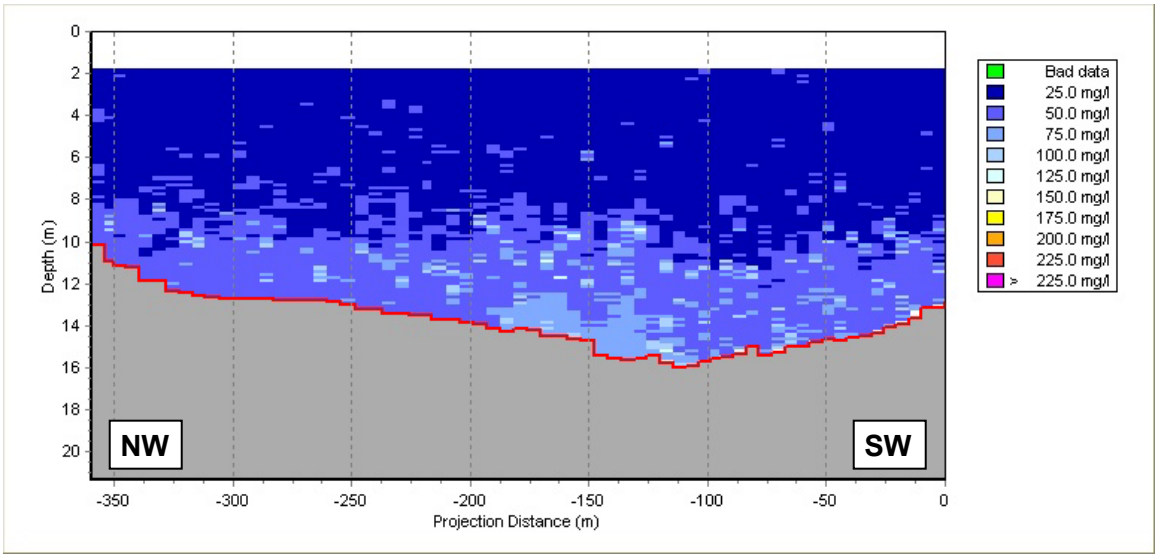

Figure 8. Vertical cross-sectional profile of acoustic estimates of "ambient" TSS on Transect 1 (approximately 450 m down-current from dredge location) during an ebbing tide survey (ODEA) in Outer Oakland Harbor.

On Transect 5, where the channel bottom was somewhat flatter and slightly shallower than Transect 1, TSS concentrations were generally below 25 mg/l throughout the water column except for along the eastern channel side slope. Total suspended sediment concentrations there were in the 50 to 75 mg/l range (Figure 9). Because the dredge was operating at this time, these TSS concentrations could have been the "front edge" of a plume. This was unlikely, however, in that the dredge was located at the opposite end of the transect.

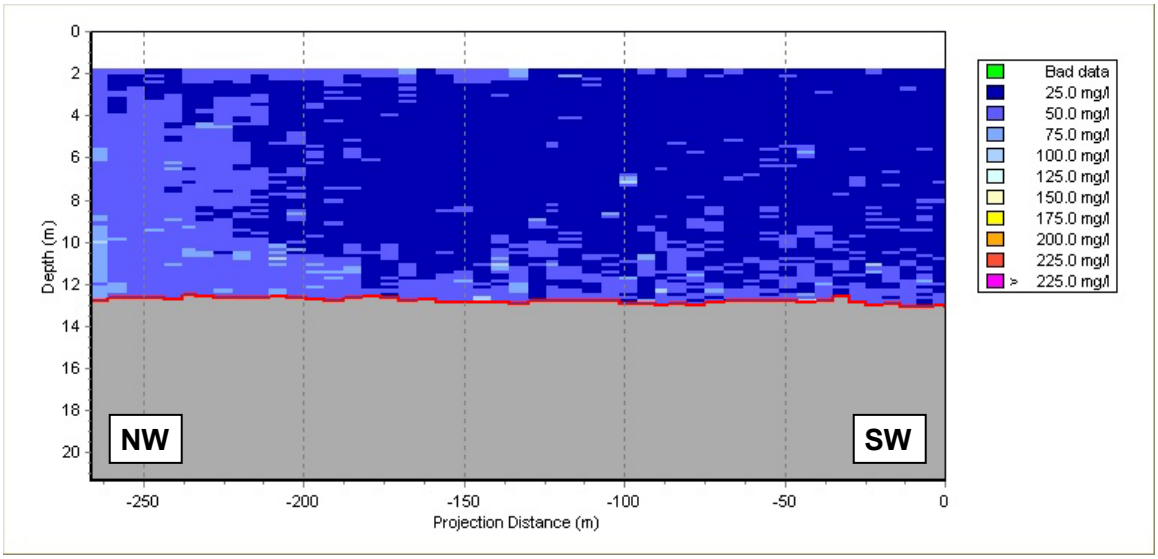

Figure 9. Vertical cross-sectional profile of acoustic estimates of "ambient" TSS on Transect 5 (approximately 100 m down-current from dredge location) during an ebbing tide survey (ODEA) in Outer Oakland Harbor.

In the inner harbor, as seen on Transect 10 in Figure 10, TSS concentrations below a depth of 8 m were almost uniformly in the 50 to 75 mg/l range. A broad area of the upper water column adjacent to the northern side slope had elevated TSS concentrations approaching 150 mg/l. It was possible that these values were influenced by prop wash, including entrained bubbles, or re-suspension due to commercial ship traffic. Elevated TSS concentrations in this parcel of surface water could conceivably have been generated by the dredge, but again, location and discontinuity from the source makes this explanation unlikely.

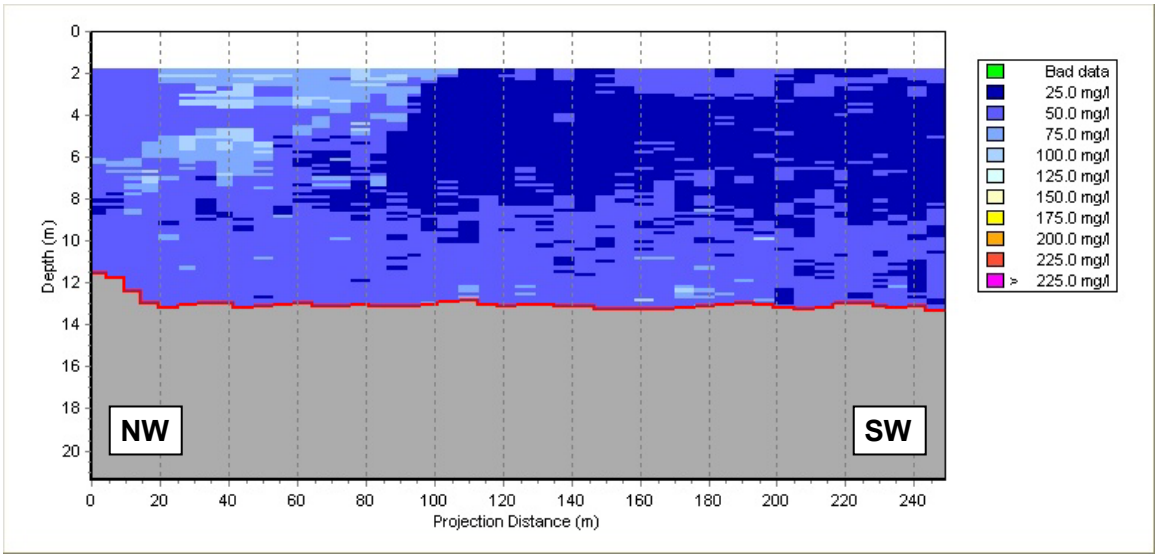

Figure 10. Vertical cross-sectional profile of acoustic estimates of "ambient" TSS on Transect 10 (approximately 300 m down-current from dredge location) during an ebbing tide survey (ODEA) in Outer Oakland Harbor.

Ebb Tide Plume Characterizations

Two during-dredging ADCP surveys (ODEC and ODED) were conducted during ebb tides. In these surveys the dredge had been in full production mode for sufficient time to generate an equilibrium plume (i.e. fully developed with maximum TSS concentration gradients and spatial dispersion). A plan-view layout of transects in Survey ODEC is shown in Figure 11. Transects 7 and 8 were shortened due to barriers created by the locations of the operating dredge and barge. With respect to depth-averaged acoustic estimates of TSS concentration, a clear plume signature can be discerned on portions of Transects 5 through 11. Although the plume would logically be expected to disperse bay-ward by ebbing flows, most of the plume "footprint" extended laterally across the harbor from the point at which the dredge was working. This lack of bay-ward dispersion can likely be attributed to the low overall flow velocities throughout the study area. The portion of the plume on the inner harbor side of the dredging operation probably represents remnants of plume carried by a preceding series of bucket cycles during the previous flood stage.

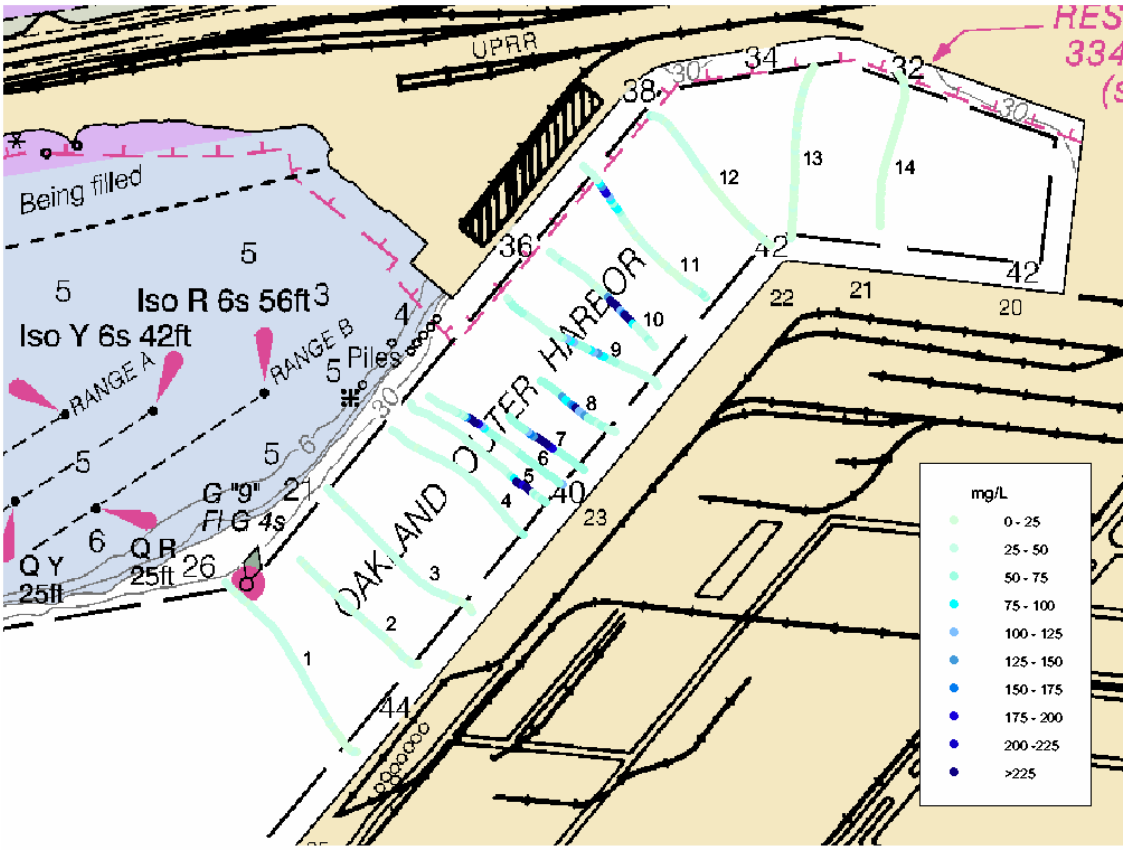

Figure 11. Locations of ADCP Survey ODEC transects in Outer Oakland Harbor during an ebbing tide. The dredge was operating adjacent to Transects 7 and 8. Depth-averaged acoustic TSS concentration estimates are indicated by color-coded dots.

Plume structure can be examined in enhanced detail in vertical cross-sectional profiles representing the series of individual transects comprising the survey (Figures 12 through 25). Transect 1 and 2 were unremarkable in that they resemble ambient conditions, with TSS concentrations above 25 mg/l confined to depths below 8 m. In Transect 3 a more diffuse distribution of TSS concentrations was seen, extending higher in the water column. These slightly elevated surface concentrations may be associated with re-suspended plume sediments lingering in the water column. The first indication of a distinct plume acoustic signature was seen on the bottom on Transect 4 (Figure 15). A band of suspended sediments about 120 m wide and up to 4 m off the bottom extends over the eastern portion of the transect, with TSS concentrations primarily in the 75 to 100 mg/l range, but as high as 150 mg/l. The same basic pattern, with slightly lower TSS concentrations, was seen on Transect 5 (Figure 16). On Transect 6, which crosses the channel immediately adjacent to the point at which the dredge bucket was transiting the water column, a very distinct, intense acoustic signature of rising gas bubbles was present (Figure 17). A separate signature of a diffuse bottom plume dispersing laterally in the lower half of the water column was also seen. Air bubbles are entrained as the bucket is lowered through the surface of the water. In currents as slow as those present at the study sites, bubbles have been shown to dissipate within 100 m or less of the source. On Transect 7 (Figure 18) a diffuse plume covers the entire lower column below a depth of 7 m, with TSS concentrations as high as 125 mg/l. Note that this transect began in mid-channel because of obstructing dredging equipment. Transect 8 was interesting in that two distinct plume

"pulses" were evident, one relatively intense and a second rather diffuse (Figure 19). The intense pulse was located approximately 150 m from the source, with TSS concentrations up to 200 mg/l, whereas TSS concentrations in the second pulse, about 100 m further away, did not exceed 125 to 150 mg/l. With distance, the plume settled deeper in the water column. These acoustic signatures clearly illustrated the non-uniform structure of the plume generated by a closed bucket dredge. Each impact of the bucket on the substratum produced a pulse of suspended sediment, which slowly drifted away. The intervening time interval between bottom impact and winching up, unloading, and winching down again is on average 50 to 70 seconds for most bucket dredging operations. Thus a new pulse is created roughly every 60 seconds. The intense pulse decays with movement away from the source as coarser fractions settle out. A residual plume of fine sediments persists for an indefinite period based on hydrodynamics and bathymetry at the site. Transects 9 and 10 (Figures 20 and 21) retain this pattern of double signatures, with decaying TSS concentrations with increasing distance. Again, it was noteworthy that these plume components were located on the harbor side of the dredging operation, although the tide was ebbing. The acoustic plume signatures were almost entirely lost on Transect 11 (Figure 22), although TSS concentrations that may be part of the residual plumes were distributed widely in the water column. Even background TSS concentrations appeared to decay progressing from Transect 12 to 14 (Figures 23 to 25). Essentially the entire water column had TSS concentrations in the 0 to 25 mg/l range on Transect 14. This may reflect the fact that current speeds at the "dead end" of the harbor channel were sufficiently slow to create a settling basin.

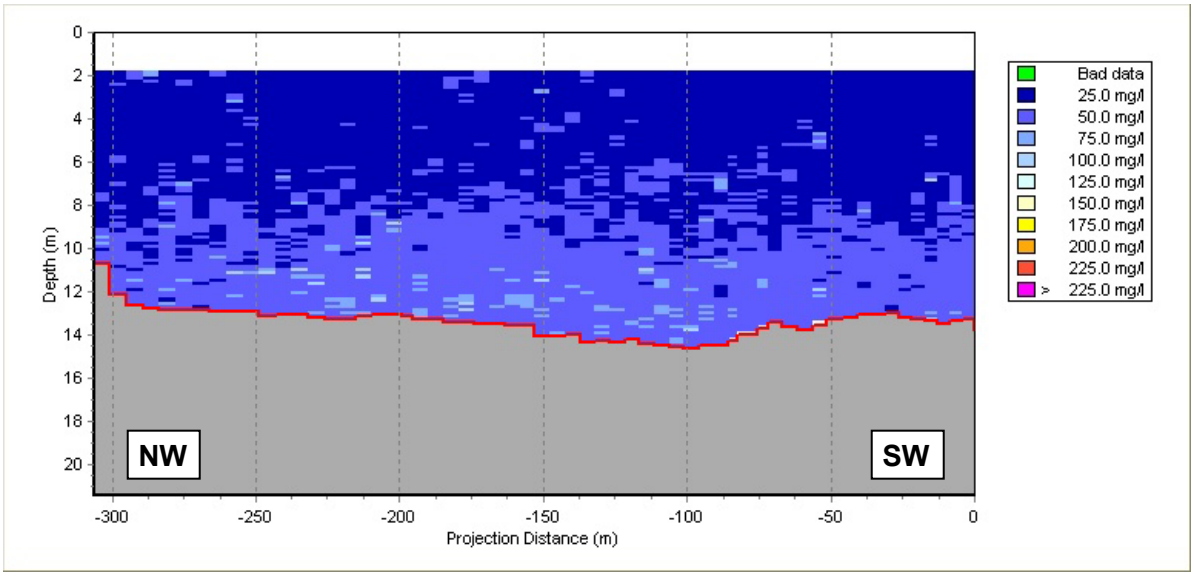

Figure 12. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 1 (approximately 300 m down-current from dredge location) during an ebbing tide survey (ODEC) in Outer Oakland Harbor.

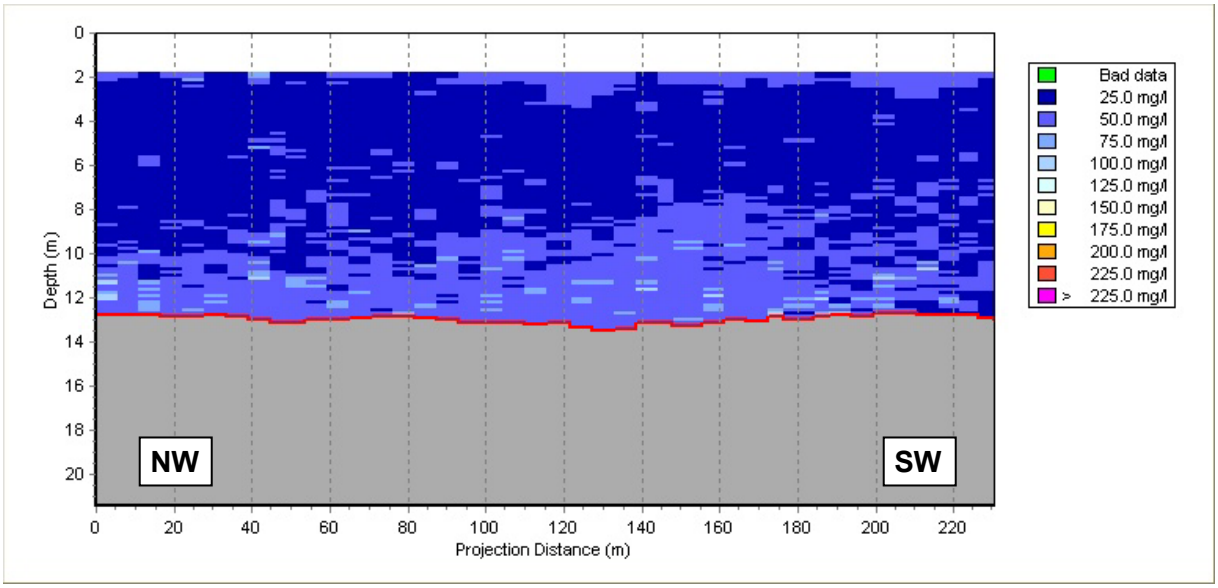

Figure 13. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 2 (approximately 250 m down-current from dredge location) during an ebbing tide survey (ODEC) in Outer Oakland Harbor.

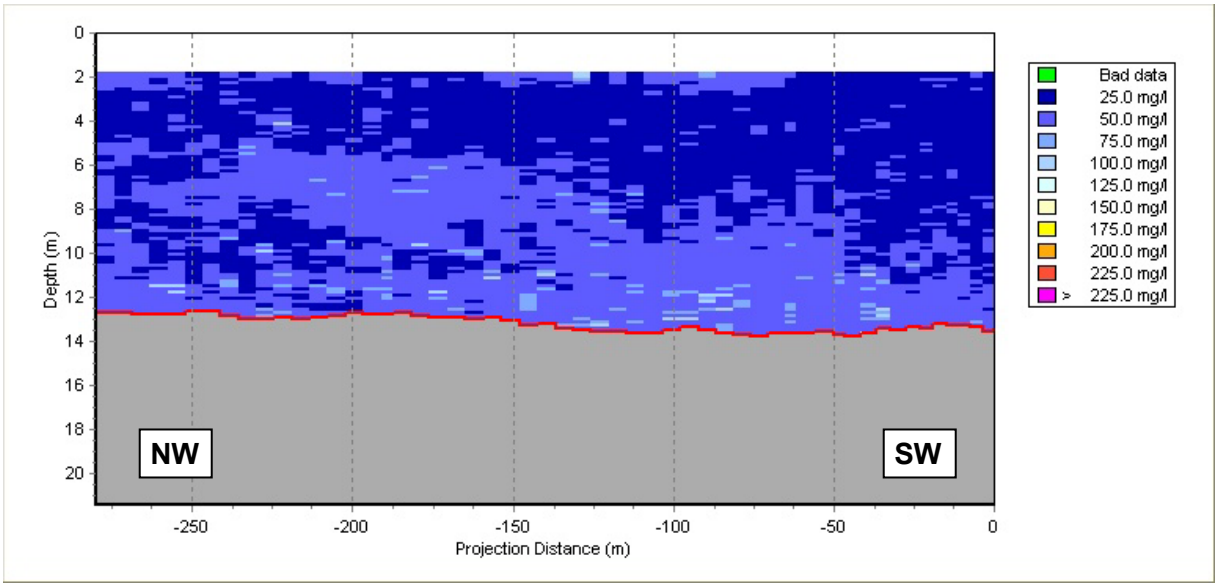

Figure 14. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 3 (approximately 200 m down-current from dredge location) during an ebbing tide survey (ODEC) in Outer Oakland Harbor.

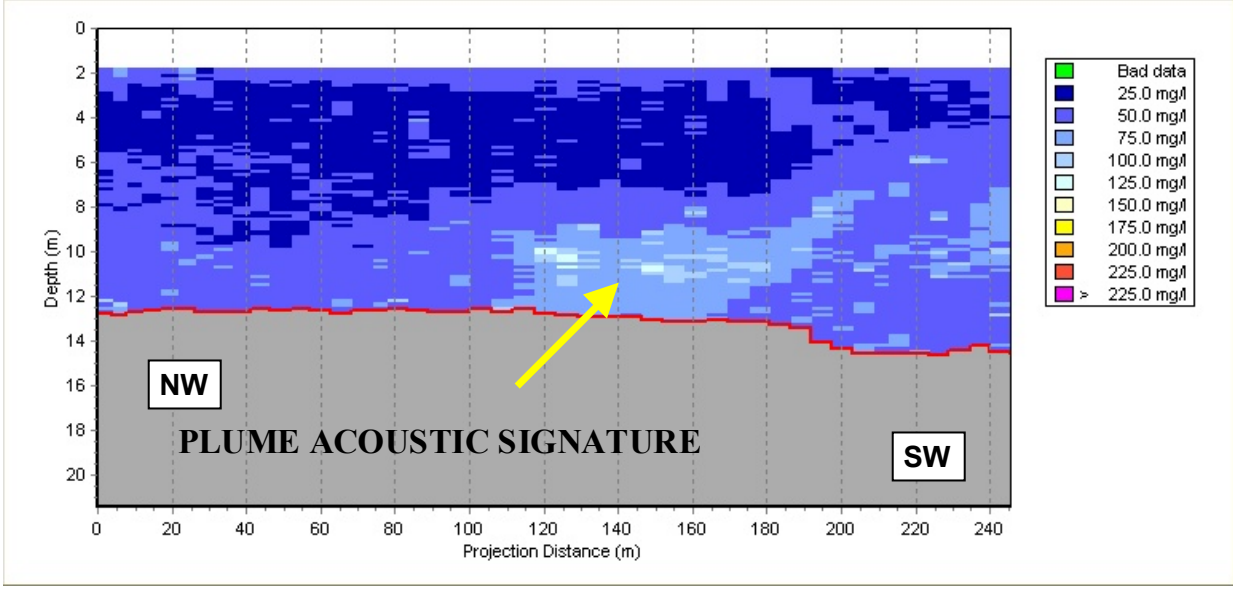

Figure 15. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 4 (approximately 100 m down-current from dredge location) during an ebbing tide survey (ODEC) in Outer Oakland Harbor.

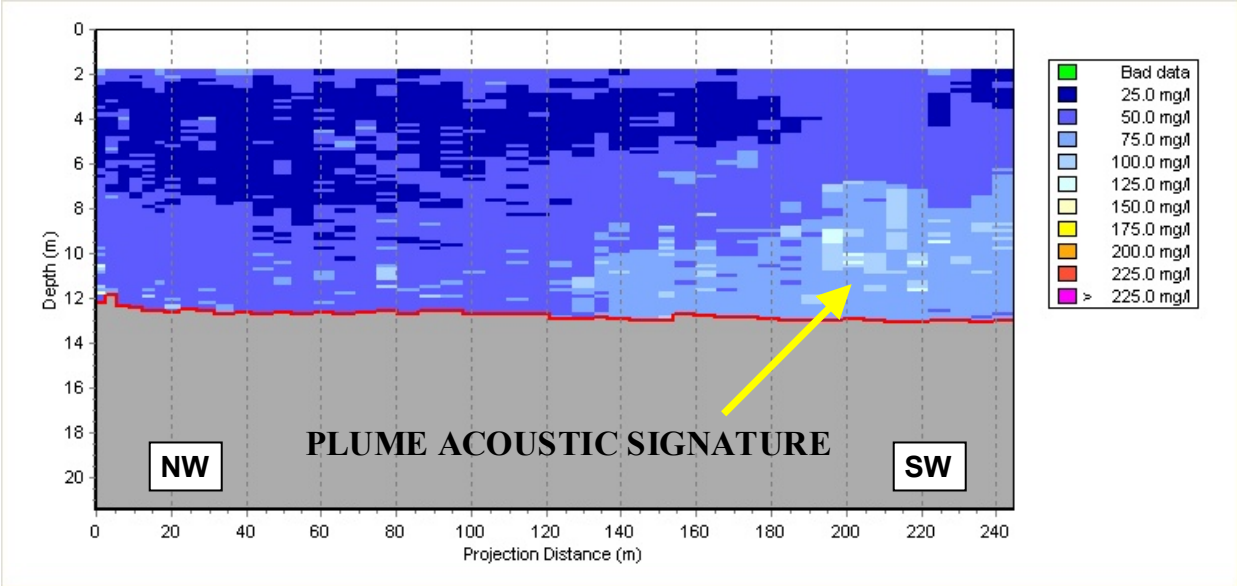

Figure 16. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 5 (approximately 75 m down-current from dredge location) during an ebbing tide survey (ODEC) in Outer Oakland Harbor.

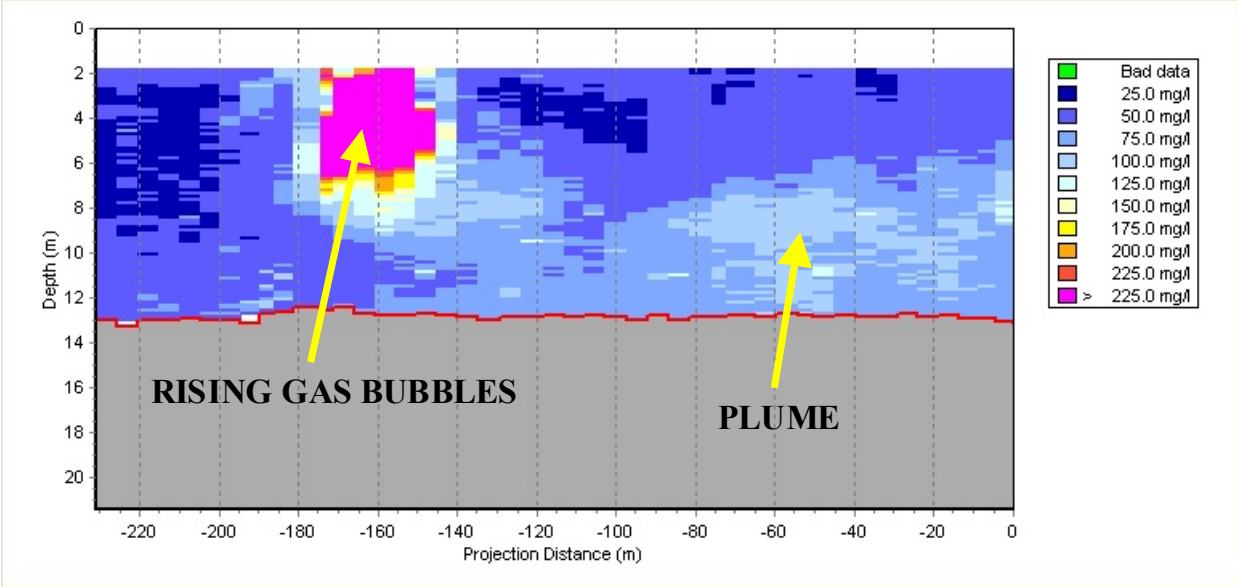

Figure 17. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 6 (approximately 50 m down-current from dredge location) during an ebbing tide survey (ODEC) in Outer Oakland Harbor.

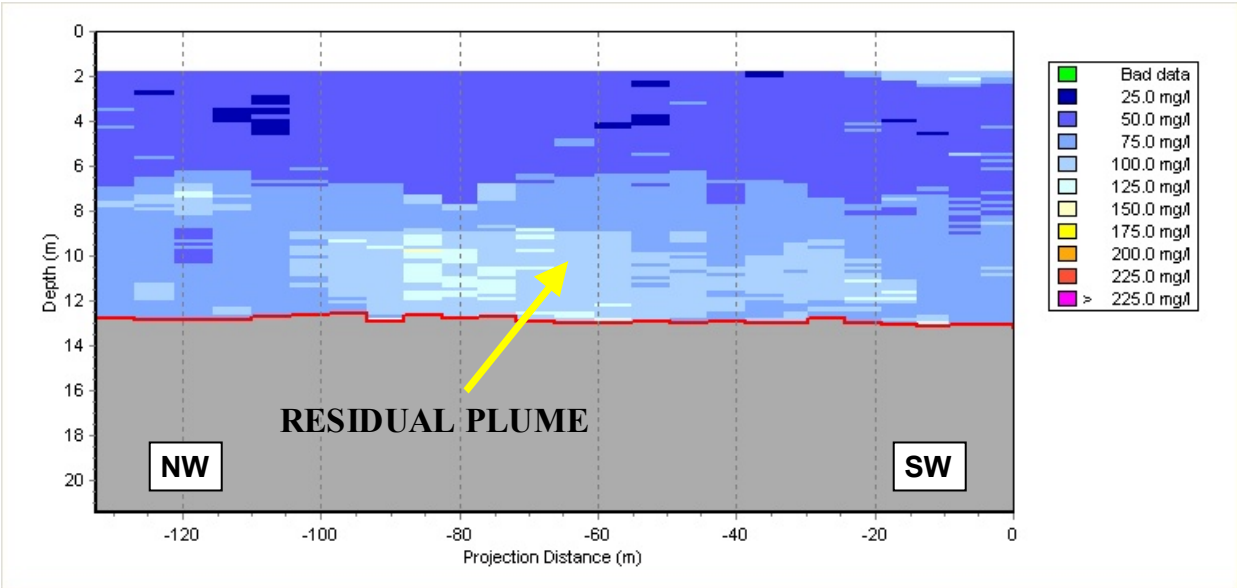

Figure 18. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 7 (approximately 25 m down-current from dredge location) during an ebbing tide survey (ODEC) in Outer Oakland Harbor.

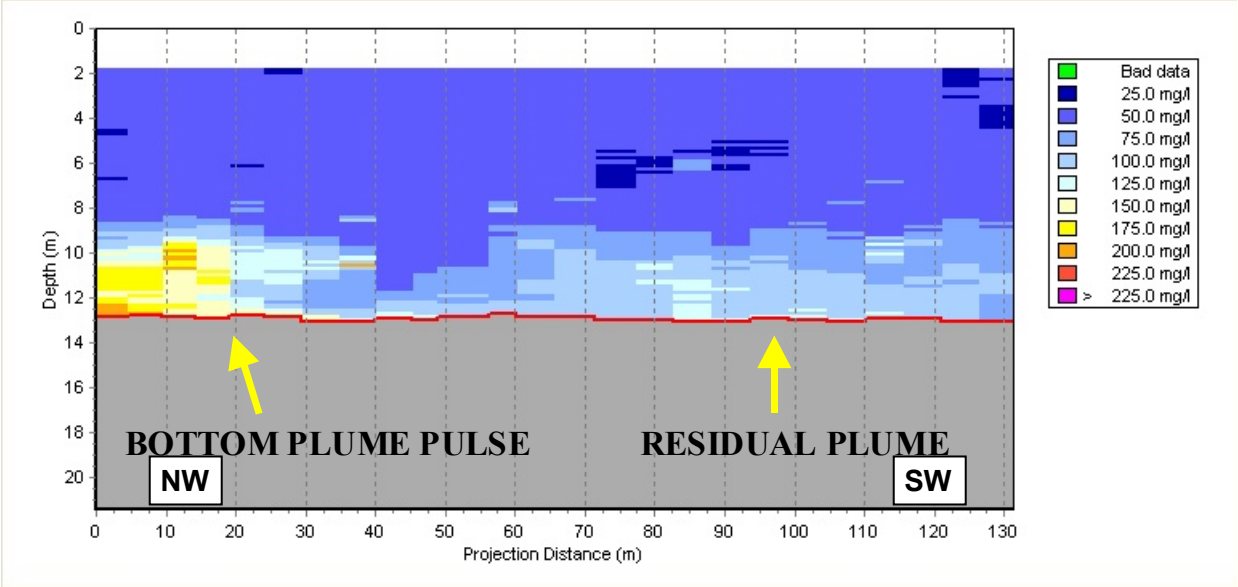

Figure 19. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 8 (approximately 25 m up-current from dredge location) during an ebbing tide survey (ODEC) in Outer Oakland Harbor.

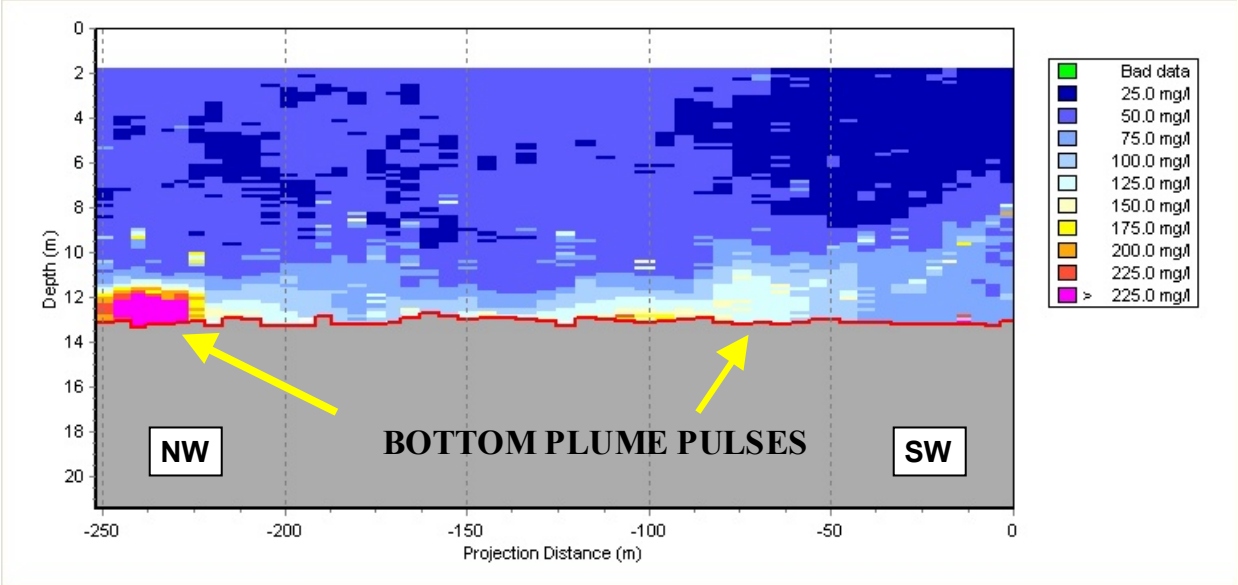

Figure 20. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 9 (approximately 75 m up-current from dredge location) during an ebbing tide survey (ODEC) in Outer Oakland Harbor.

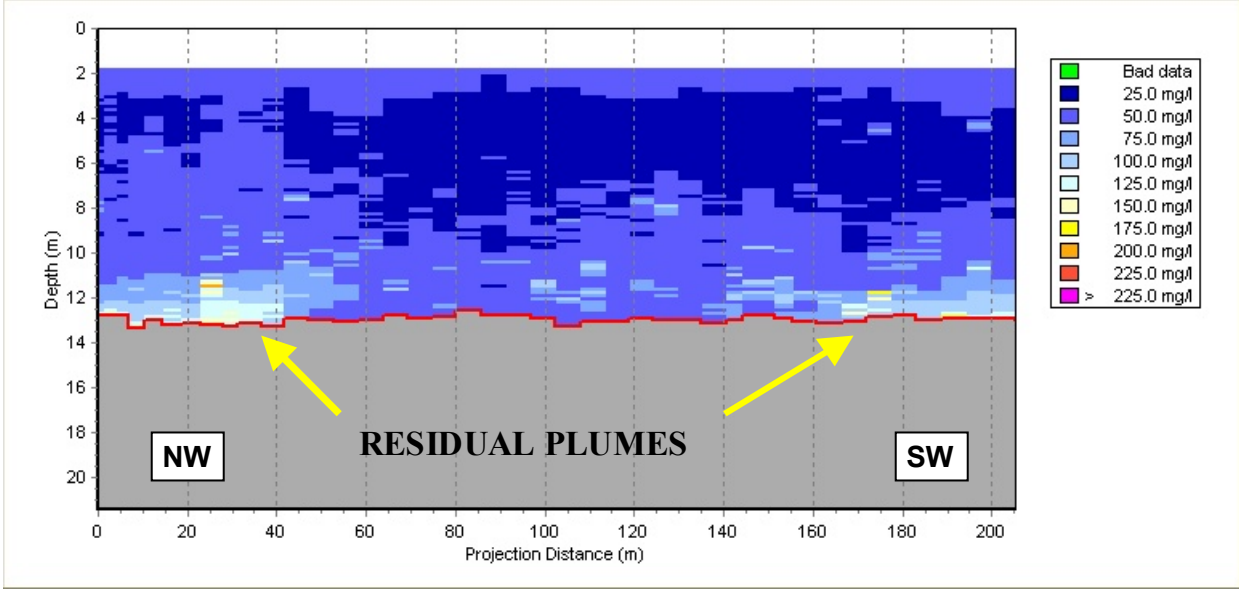

Figure 21. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 10 (approximately 150 m up-current from dredge location) during an ebbing tide survey (ODEC) in Outer Oakland Harbor.

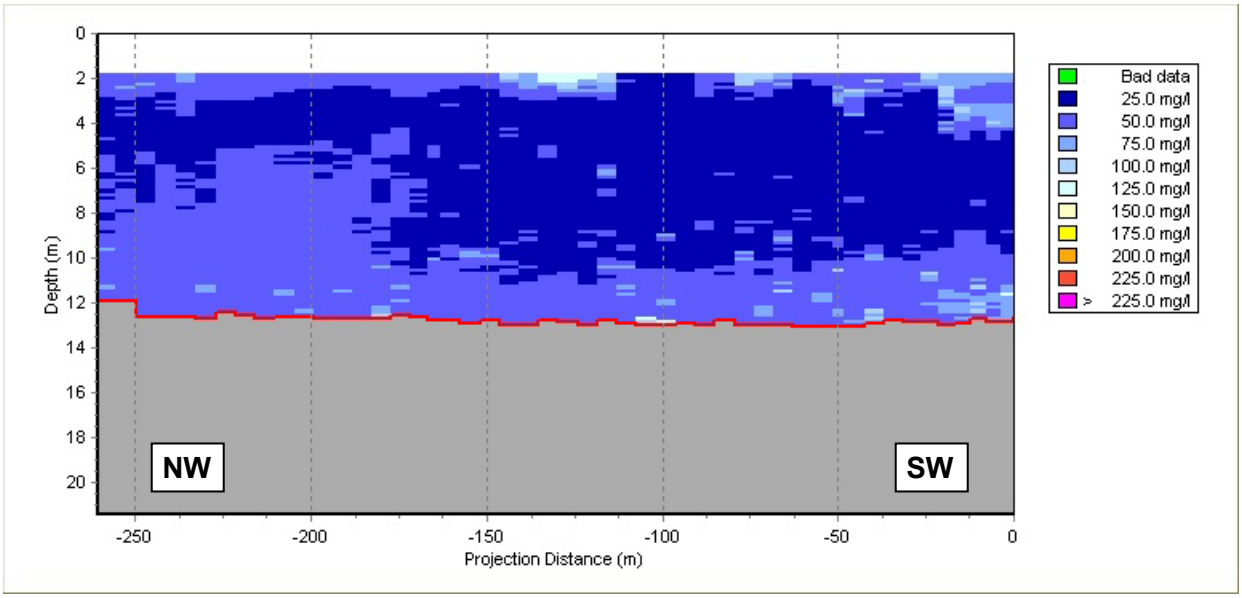

Figure 22. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 11 (approximately 200 m up-current from dredge location) during an ebbing tide survey (ODEC) in Outer Oakland Harbor.

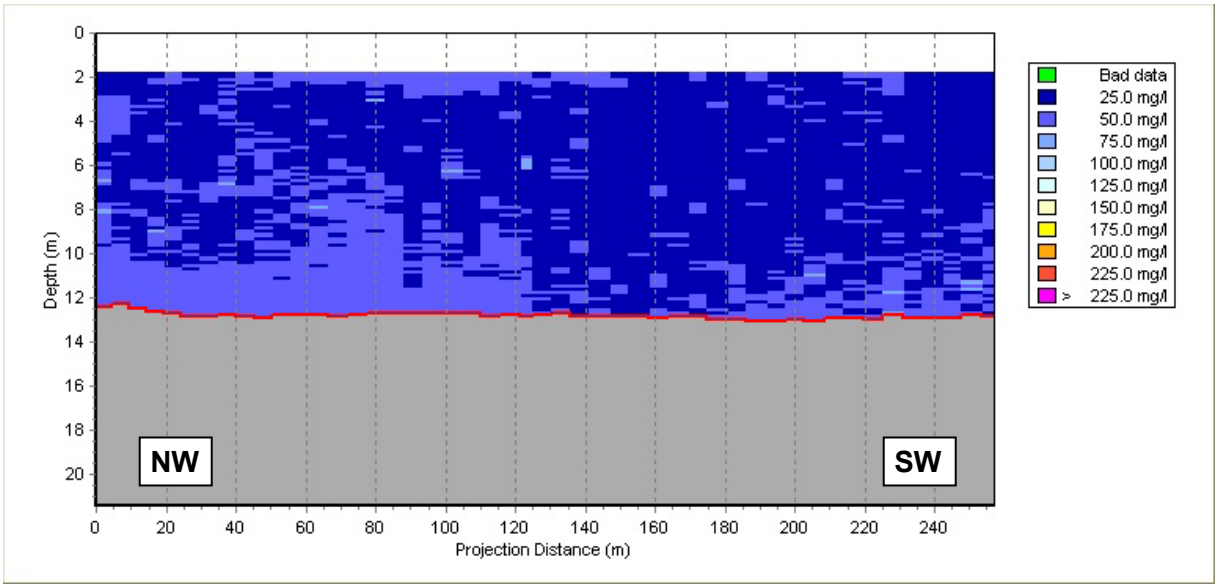

Figure 23. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 12 (approximately 300 m up-current from dredge location) during an ebbing tide survey (ODEC) in Outer Oakland Harbor.

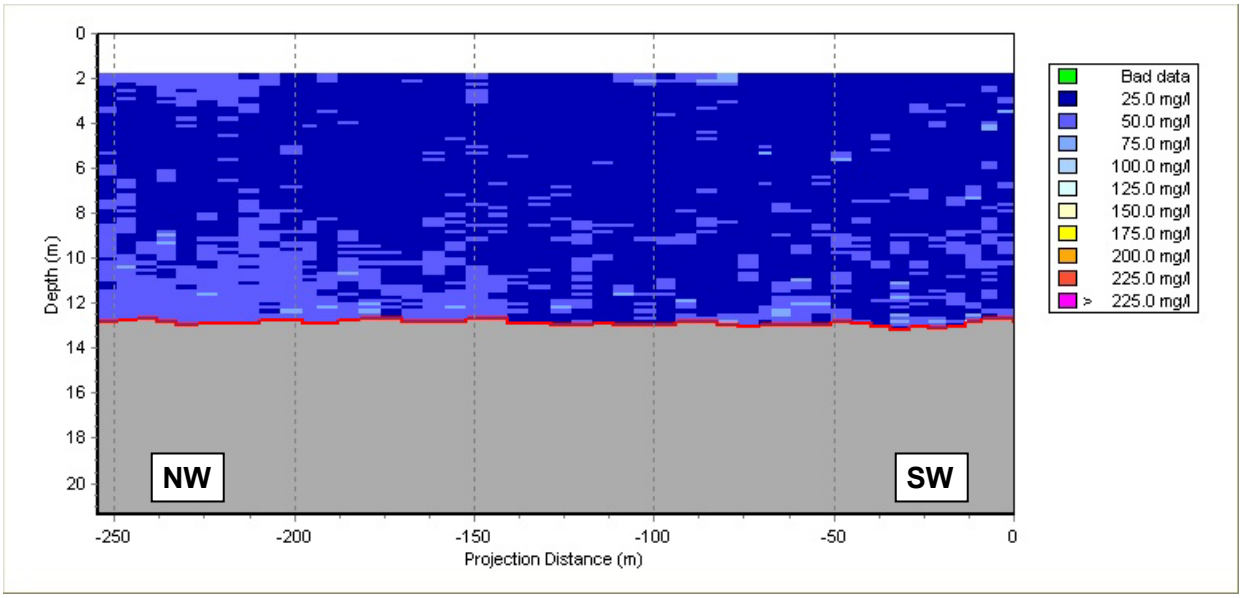

Figure 24. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 13 (approximately 400 m up-current from dredge location) during an ebbing tide survey (ODEC) in Outer Oakland Harbor.

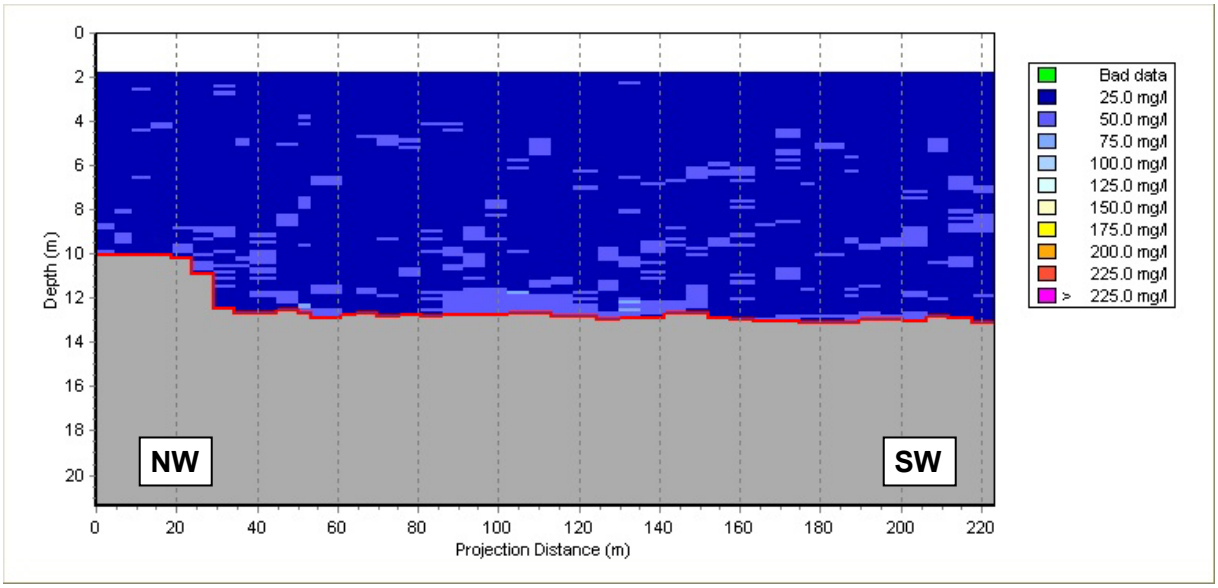

Figure 25. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 14 (approximately 500 m up-current from dredge location) during an ebbing tide survey (ODEC) in Outer Oakland Harbor.

A second during-dredging ebb tide survey (ODED) produced similar results. A plan-view layout of the survey transects is given in Figure 26. Distances between parallel transects were reduced to gain better resolution of plume features near the source. Examination of the vertical cross-sectional profiles comprising the survey again indicated that the plume was a heterogeneous feature, with pulses of re-suspended sediment moving away from the source. Transects 1 and 2 (Figures 27 and 28) showed a progressive coverage of TSS concentrations in the 25 to 50 mg/l range with movement toward the dredge. In this survey, some appearance of a mid-water plume was found on Transects 3 and 4 (Figures 29 and 30). A band of elevated TSS concentrations (up to 125 mg/l) approximately 125 m wide and 5 to 9 m deep occurred in the central portion of the channel. Intense gas bubble acoustic signatures were evident on both Transects 5 and 6 (Figures 31 and 32), which crossed the channel on the immediate ebb side of the dredge. A less intense plume signature was seen in the lower portion of the water column on Transect 5, about 125 m wide, and containing TSS concentrations up to 125 mg/l. Moving lateral to the dredge, relatively intense (up to 200 mg/l) bottom plume signatures occurred on Transects 7 and 8 (Figures 33 and 34). The plume was confined largely to depths below 8 m on Transect 8. Double plume pulses just above the substrate were seen on Transect 9 (Figure 35), where TSS concentrations decayed to approximately 125 mg/l. More diffuse bands of elevated TSS concentration were evident along Transects 10 and 11 (Figures 36 and 37) and were generally restricted to depths greater than 10 m. A double plume pulse reappeared on Transect 12, including a small signature of TSS concentration as high as 200 mg/l (Figure 38). A small plume signature was detected on the final transect, Transect 13 (Figure 39), where a central pulse showed signs of decay to TSS concentrations in the 75 to 100 mg/l range. This transect, on the harbor side of the dredge, was approximately 200 m from the source. Likewise, the plume was detected approximately 200 m away from the dredge on the bay side. Currents again appeared too weak to carry the plume substantial distances.

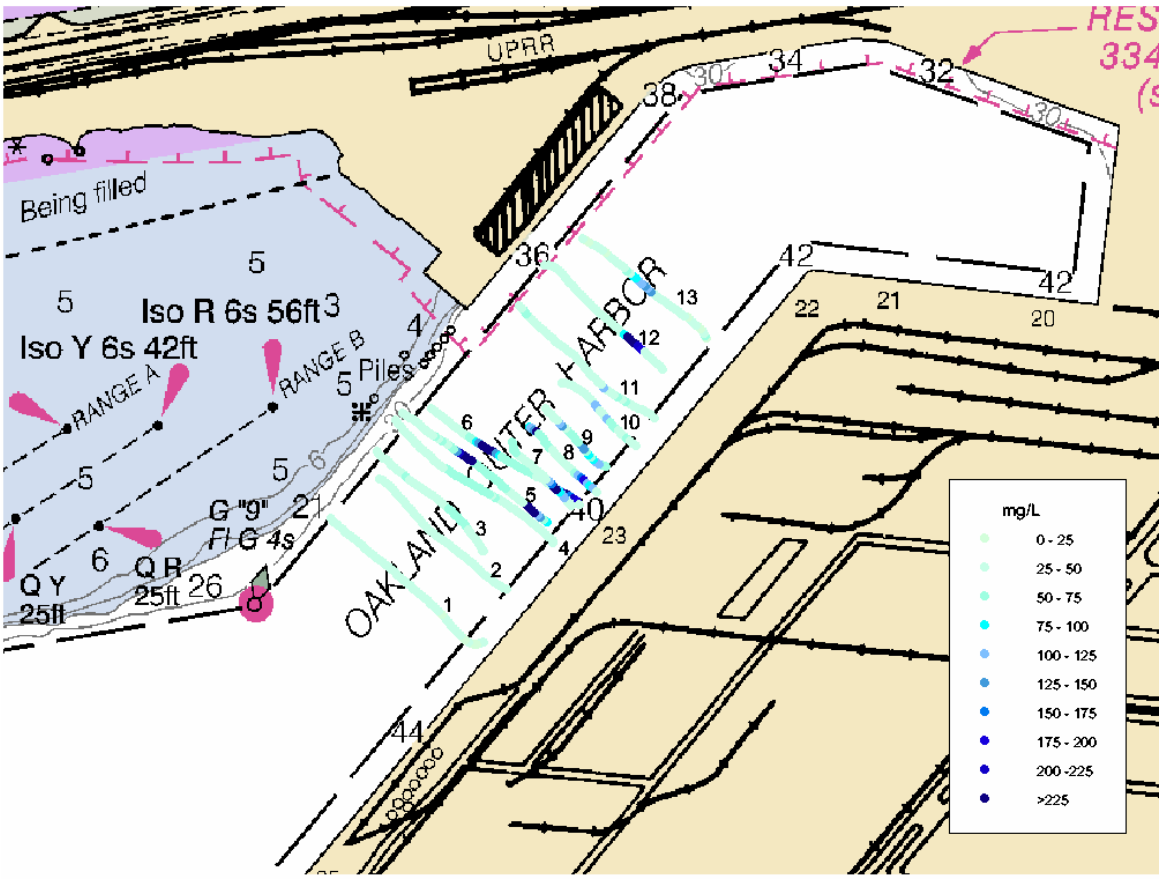

Figure 26. Locations of ADCP Survey ODED transects in Outer Oakland Harbor during an ebbing tide. The dredge was operating adjacent to Transects 7, 8, 9 and 10. Depth-averaged acoustic TSS concentration estimates are indicated by color-coded dots.

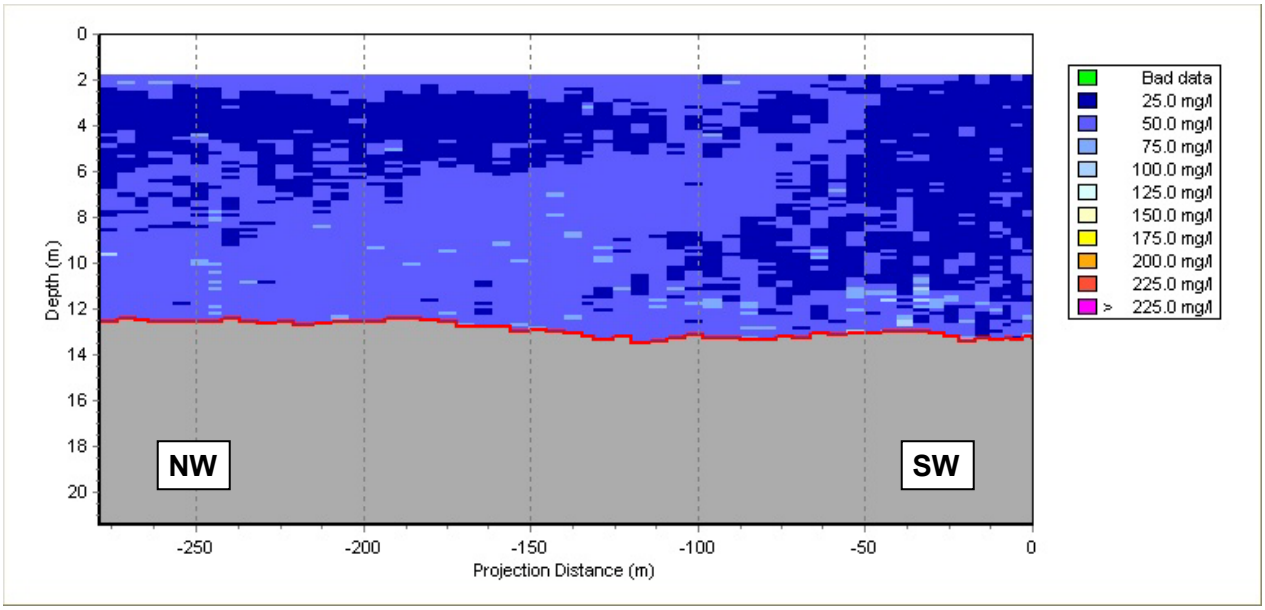

Figure 27. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 1 (approximately 200 m down-current from dredge location) during an ebbing tide survey (ODED) in Outer Oakland Harbor.

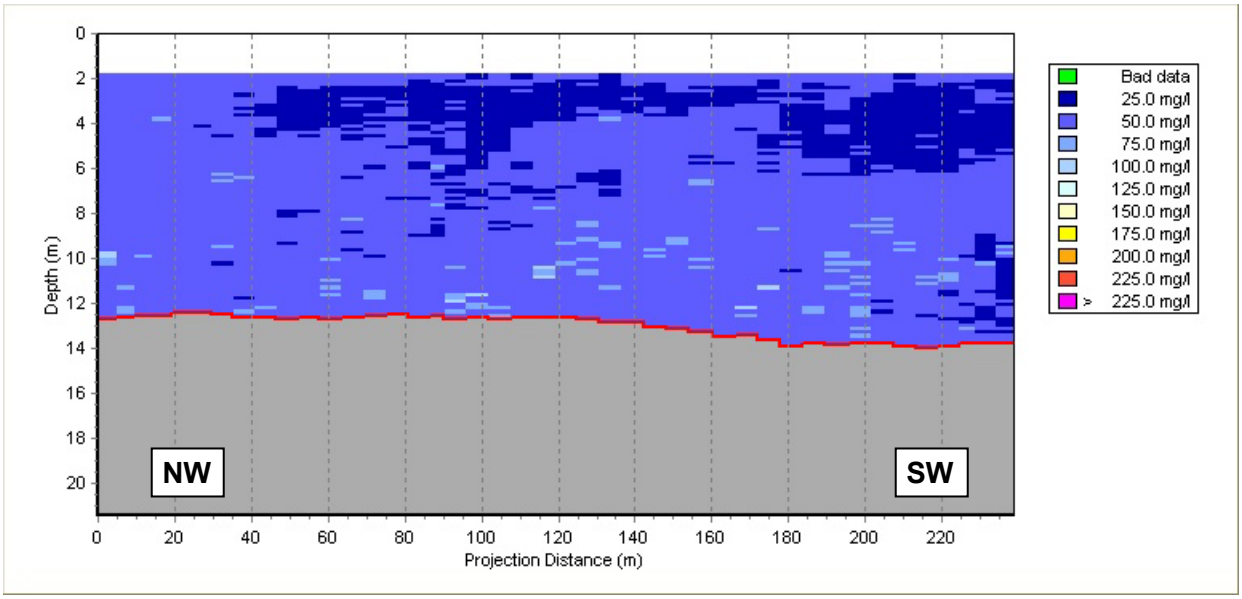

Figure 28. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 2 (approximately 150 m down-current from dredge location) during an ebbing tide survey (ODED) in Outer Oakland Harbor.

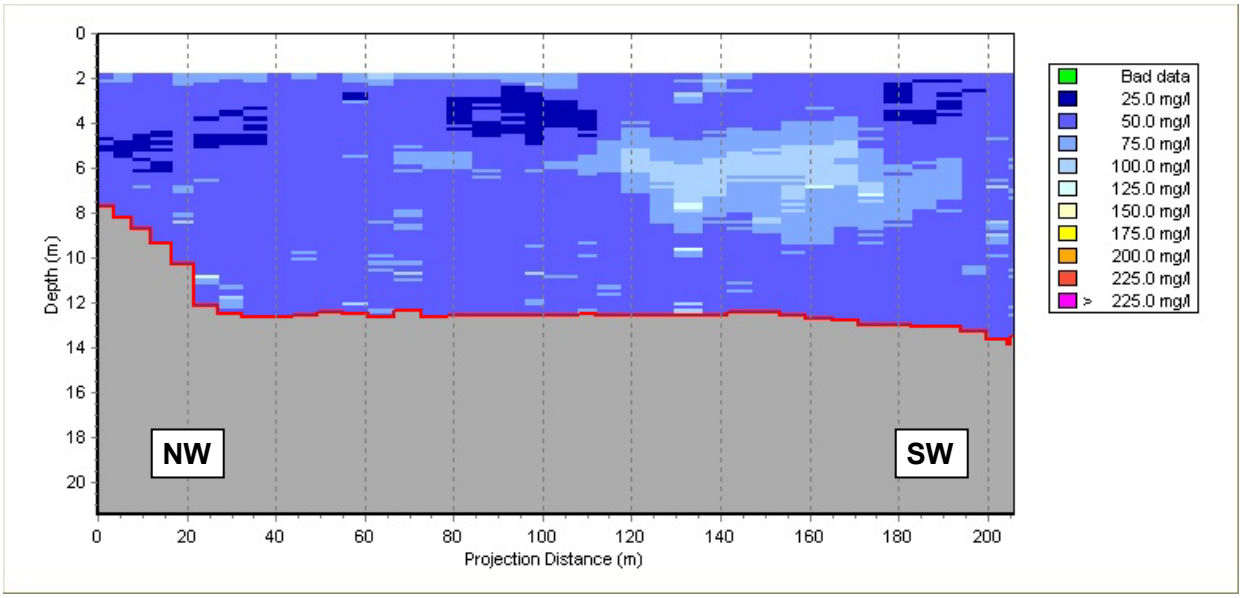

Figure 29. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 3 (approximately 125 m down-current from dredge location) during an ebbing tide survey (ODED) in Outer Oakland Harbor.

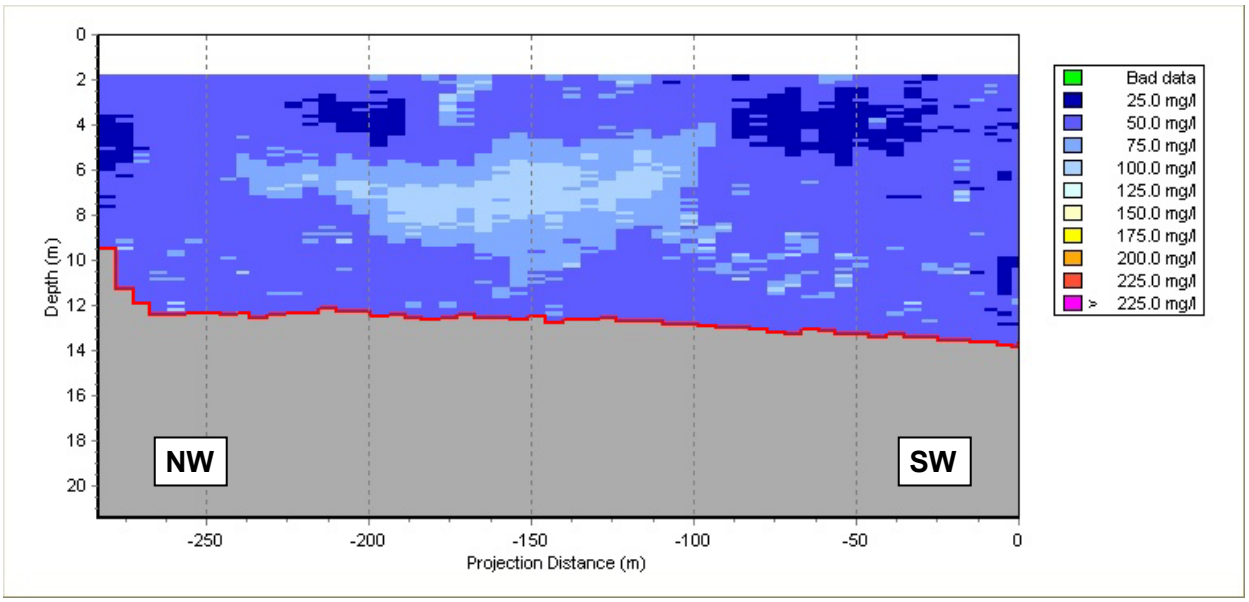

Figure 30. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 4 (approximately 100 m down-current from dredge location) during an ebbing tide survey (ODED) in Outer Oakland Harbor.

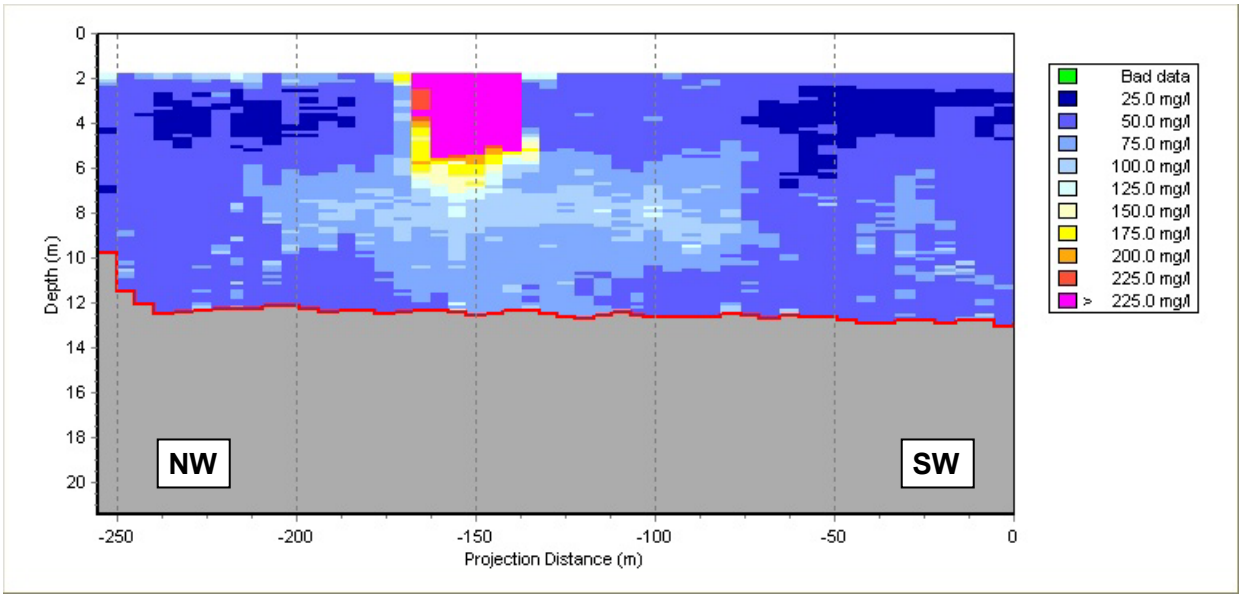

Figure 31. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 5 (approximately 75 m down-current from dredge location) during an ebbing tide survey (ODED) in Outer Oakland Harbor.

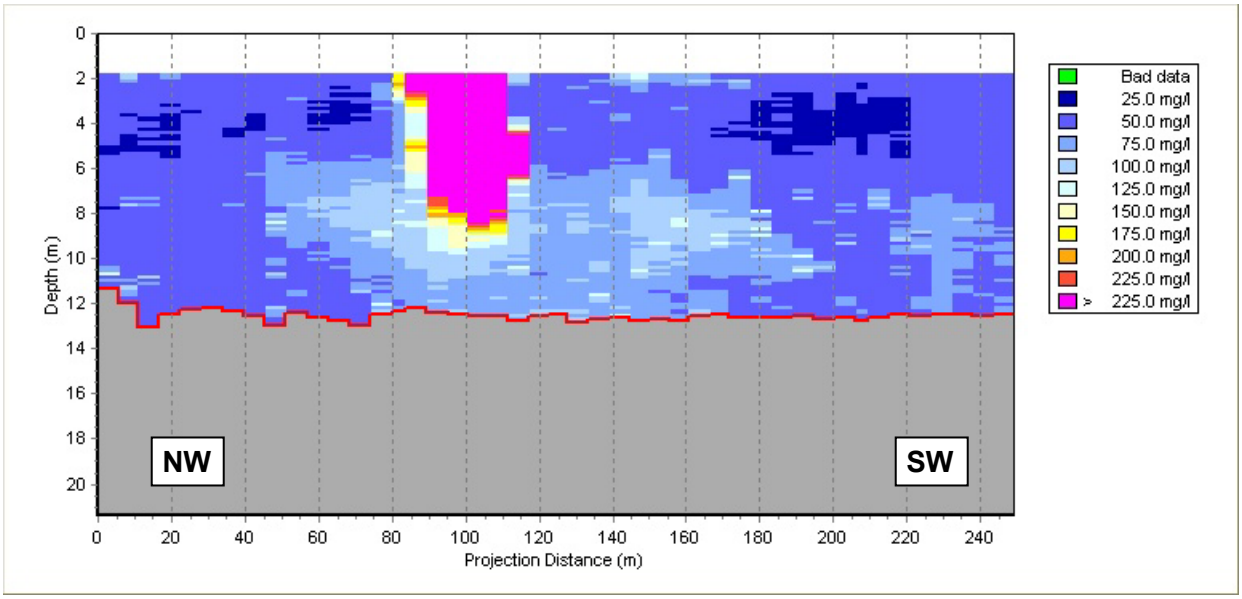

Figure 32. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 6 (approximately 50 m down-current from dredge location) during an ebbing tide survey (ODED) in Outer Oakland Harbor.

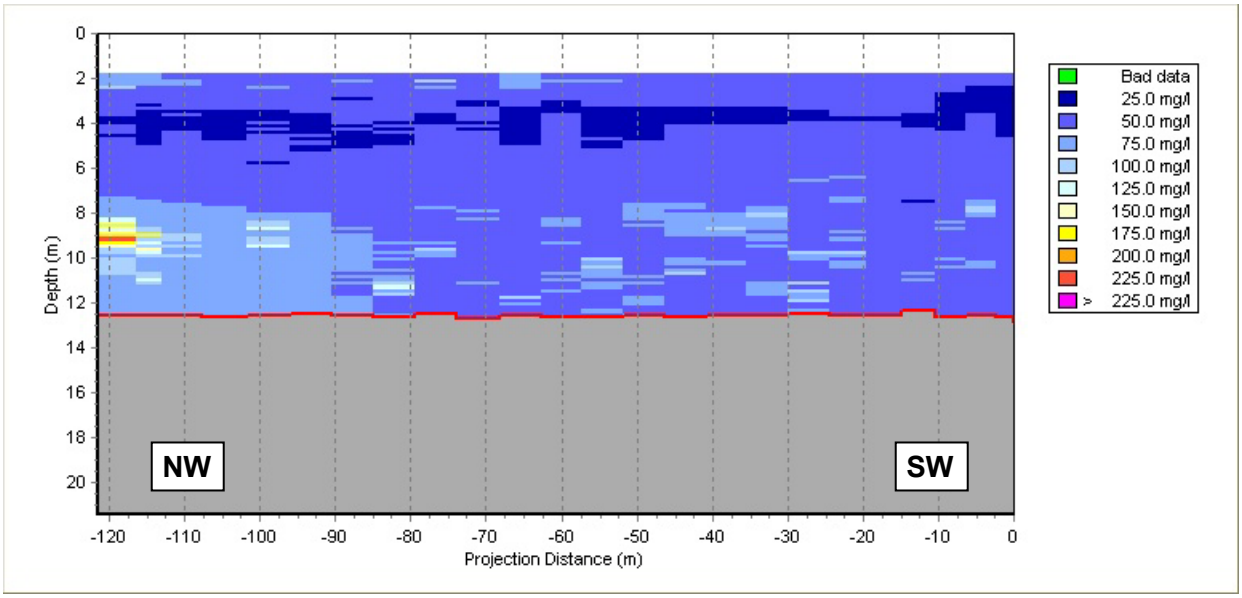

Figure 33. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 7 (approximately 25 m down-current from dredge location) during an ebbing tide survey (ODED) in Outer Oakland Harbor.

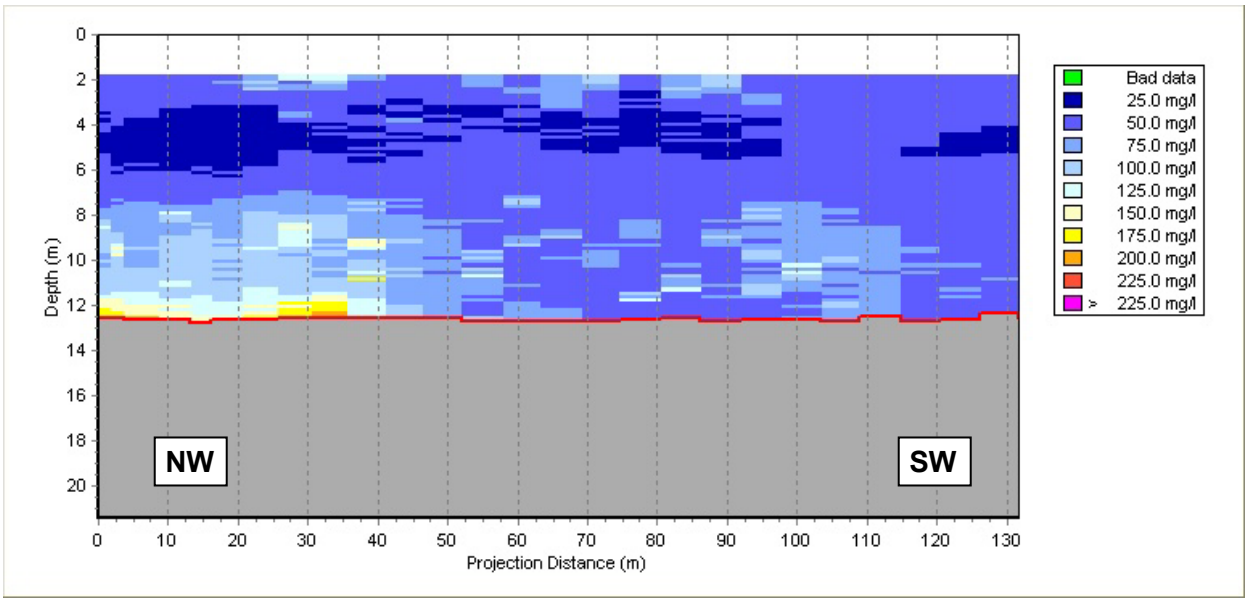

Figure 34. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 8 (adjacent to dredge location) during an ebbing tide survey (ODED) in Outer Oakland Harbor.

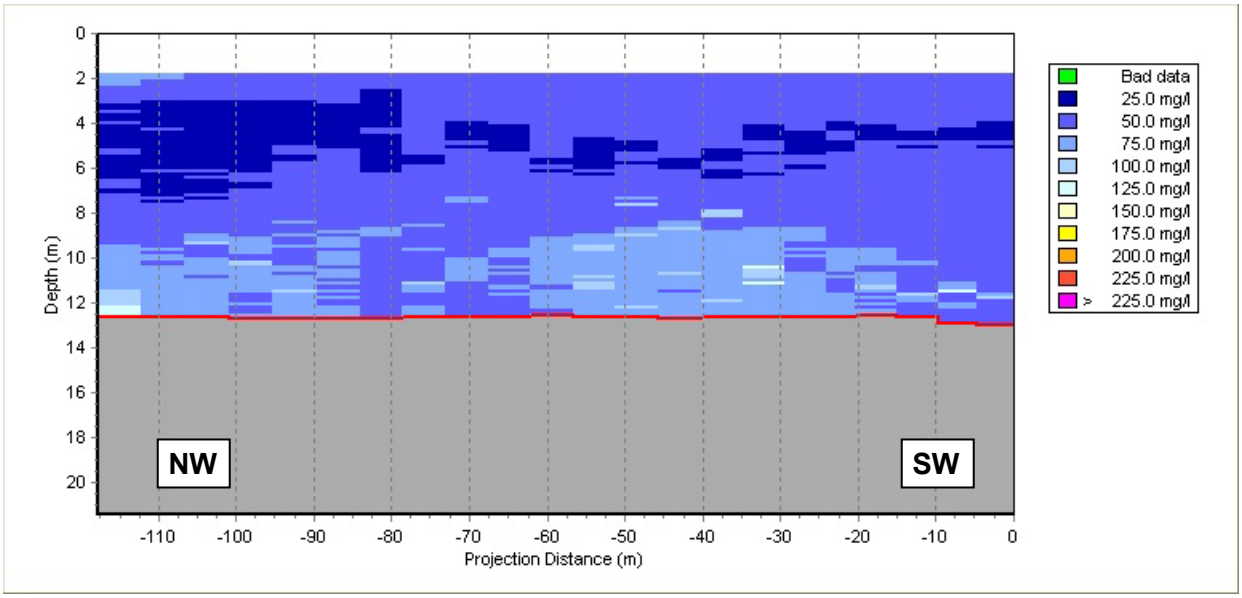

Figure 35. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 9 (approximately 25 m up-current from dredge location) during an ebbing tide survey (ODED) in Outer Oakland Harbor.

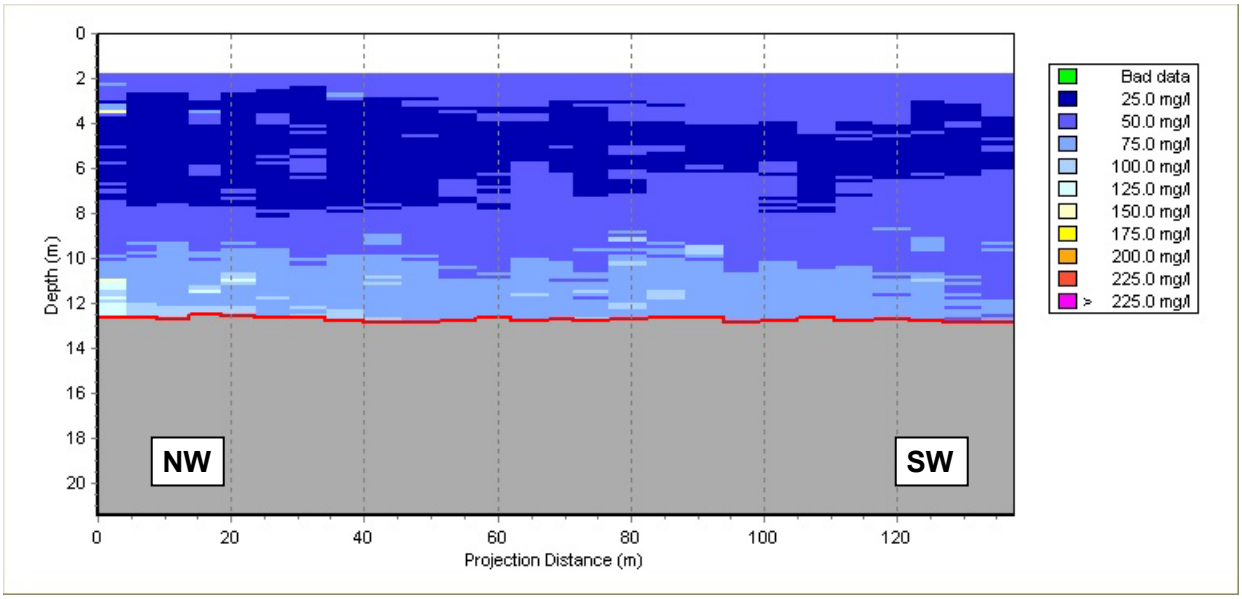

Figure 36. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 10 (approximately 50 m up-current from dredge location) during an ebbing tide survey (ODED) in Outer Oakland Harbor.

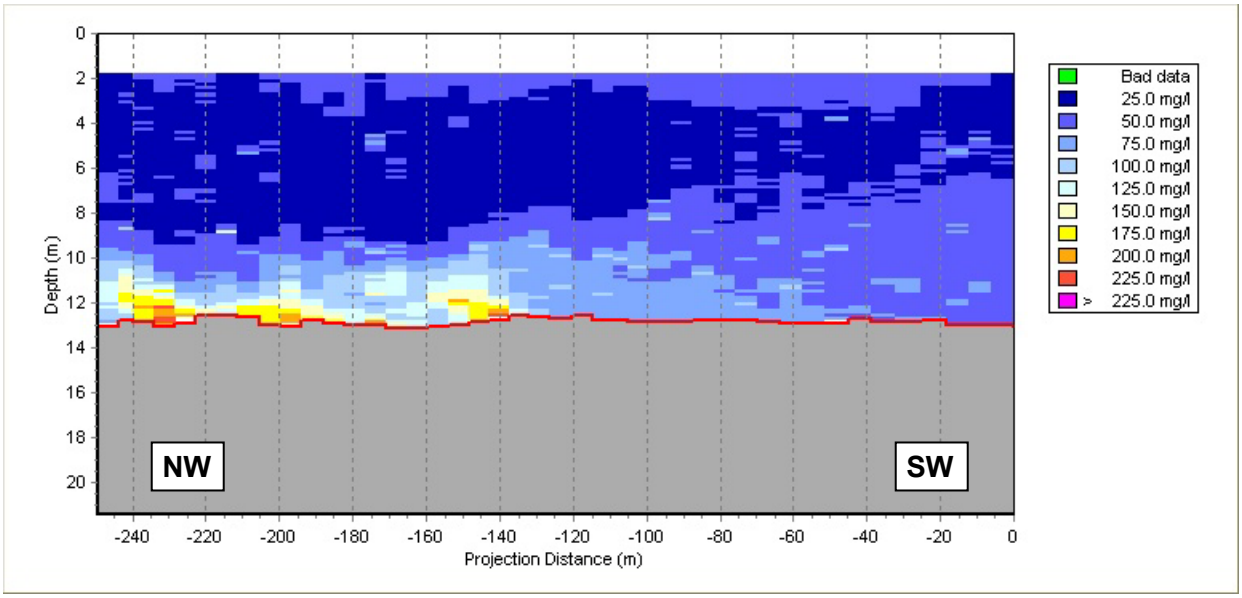

Figure 37. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 11 (approximately 75 m up-current from dredge location) during an ebbing tide survey (ODED) in Outer Oakland Harbor.

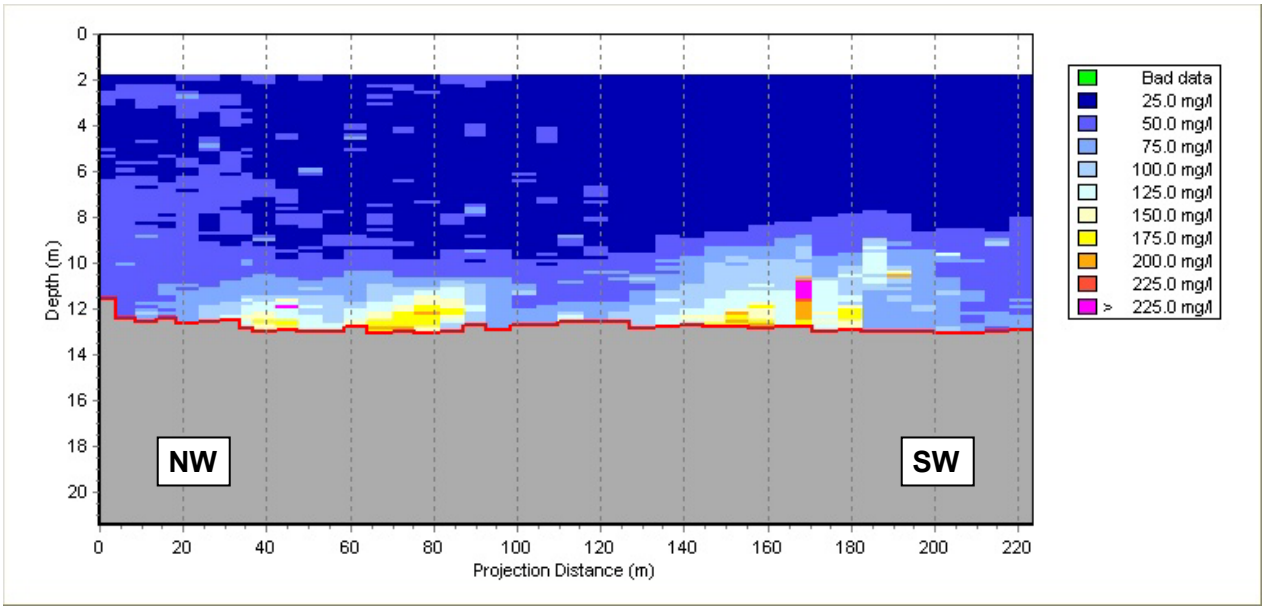

Figure 38. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 12 (approximately 125 m up-current from dredge location) during an ebbing tide survey (ODED) in Outer Oakland Harbor.

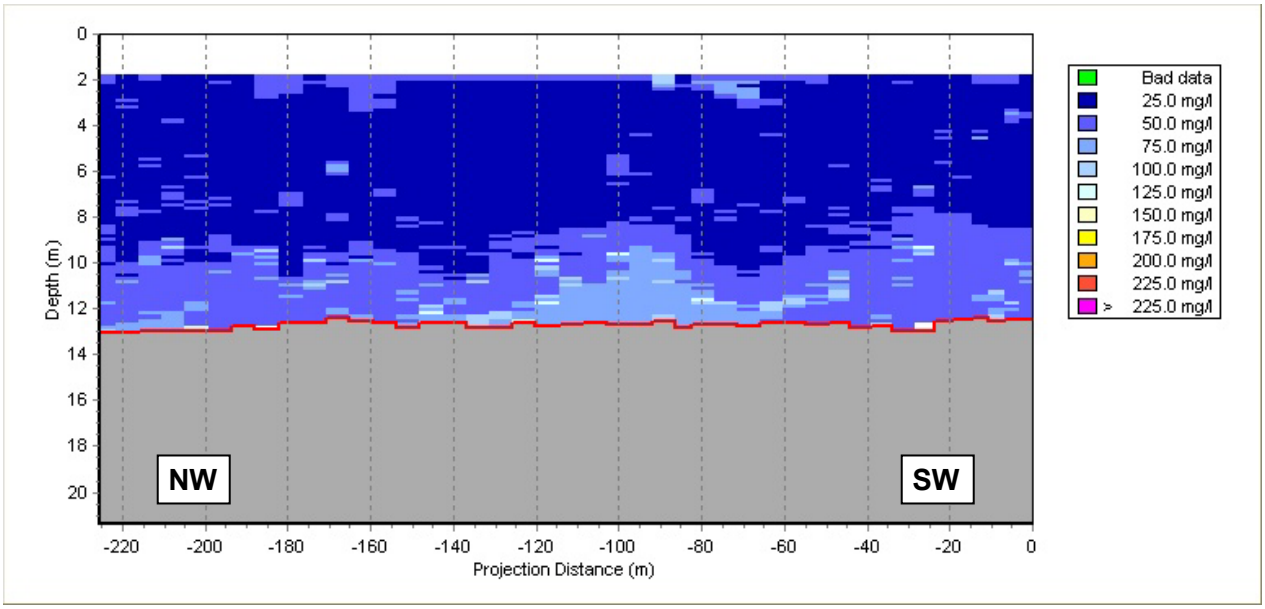

Figure 39. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 13 (approximately 150 m up-current from dredge location) during an ebbing tide survey (ODED) in Outer Oakland Harbor.

As these last three examples have shown, the ability to obtain TSS data from ADCP technology along a transect and throughout the entire water column results in the ability to resolve the temporal and spatial characteristics of sediment plumes related to dredging operations. The results along individual transects for a survey can be combined to render a three-dimensional model of the plume at varying TSS concentrations. For the last survey discussed (ODED), X, Y, Z and TSS data for all 13 transects were combined into a single digital file and modeled with GMS software (developed by Brigham Young University and funded by the USACE) to generate a three-dimensional view of the plume (Figures 40 - 42). Figure 40 shows the extent of the plume with concentrations equal to or greater than 50 mg/l. Similarly, Figures 41 and 42 show the extent of the plume with concentrations equal to or greater than 100 mg/l and 150 mg/l, respectively. The view is from the south-southeast looking towards the north-northwest. The entrance to the Oakland Outer Harbor and San Francisco Bay is on the left of the figure with the inner harbor on the right.

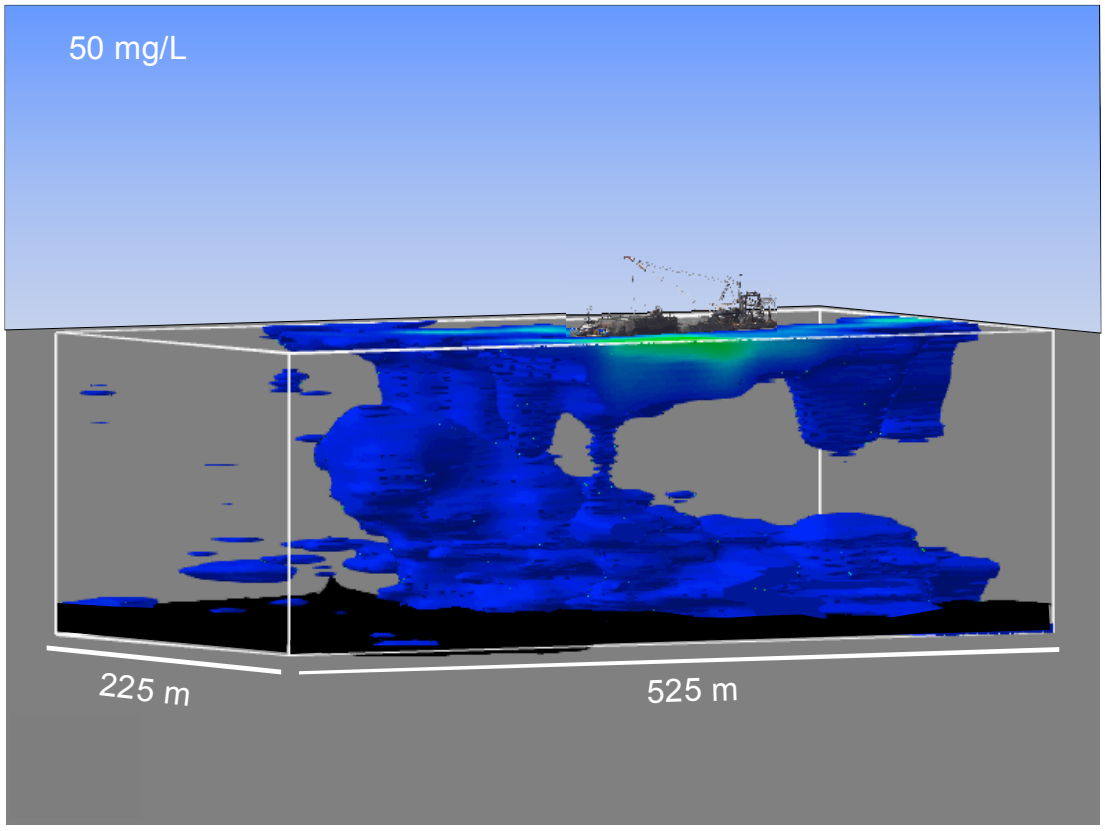

Figure 40. Three-dimensional rendering of TSS estimates greater than 50 mg/l for an entire ebbing survey (ODED) in Outer Oakland Harbor.

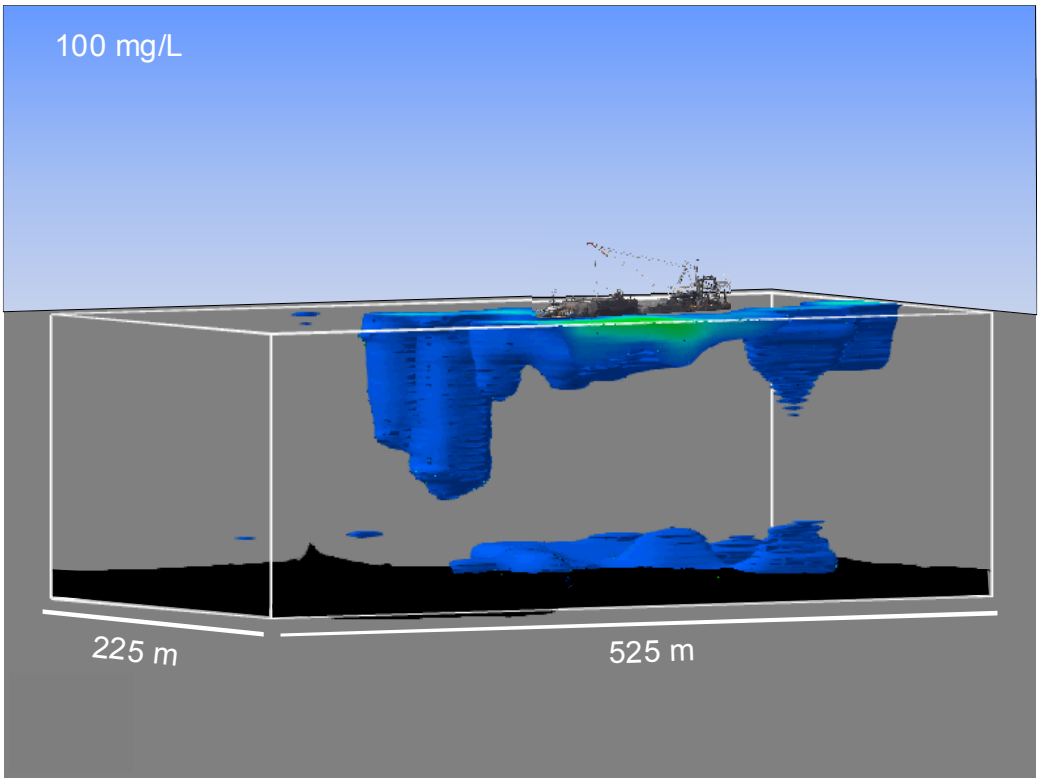

Figure 41. Three-dimensional rendering of TSS estimates greater than 100 mg/l for an entire ebbing survey (ODED) in Outer Oakland Harbor.

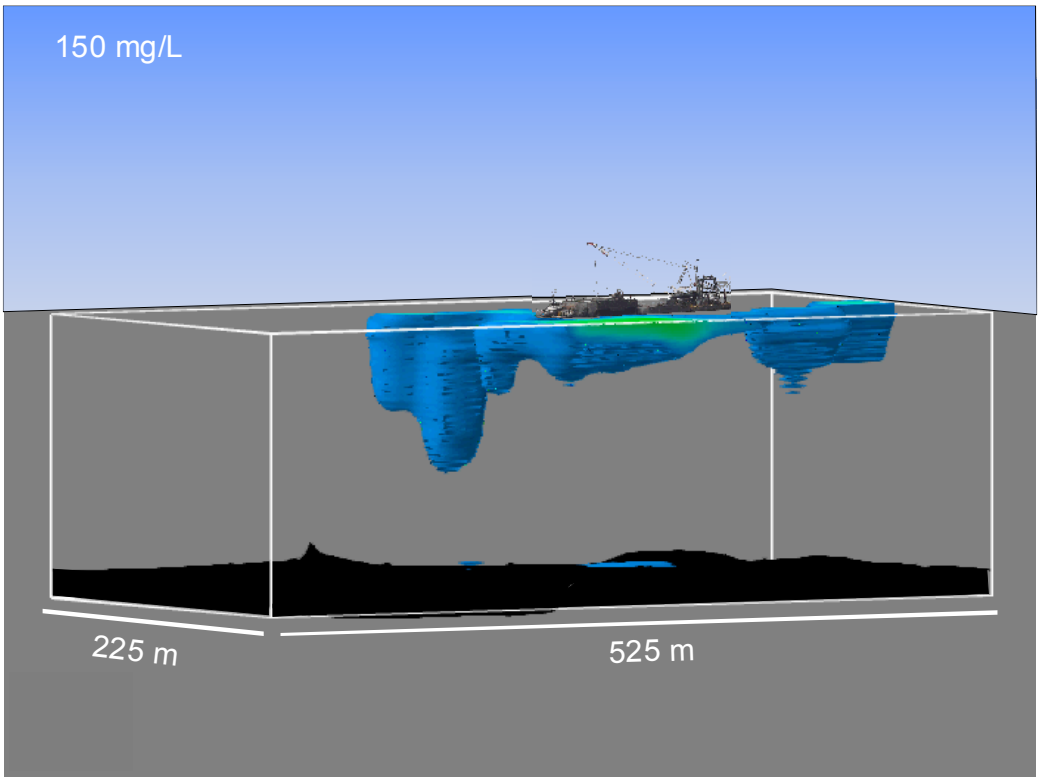

Figure 42. Three-dimensional rendering of TSS estimates greater than 150 mg/l for an entire ebbing survey (ODED) in Outer Oakland Harbor.

Flood Tide Plume Characterizations

Two during-dredging ADCP surveys (ODFC and ODFD) were completed during flooding tides. A plan-view layout of transect locations is given in Figure 43. Depth averaged acoustic estimates of TSS concentrations indicated the presence of a plume between Transect 3, just bay-ward of the dredge, and Transect 10, where the channel turns into the inner harbor area. Vertical cross-sectional profiles of TSS concentration are presented in Figures 44 through 56.

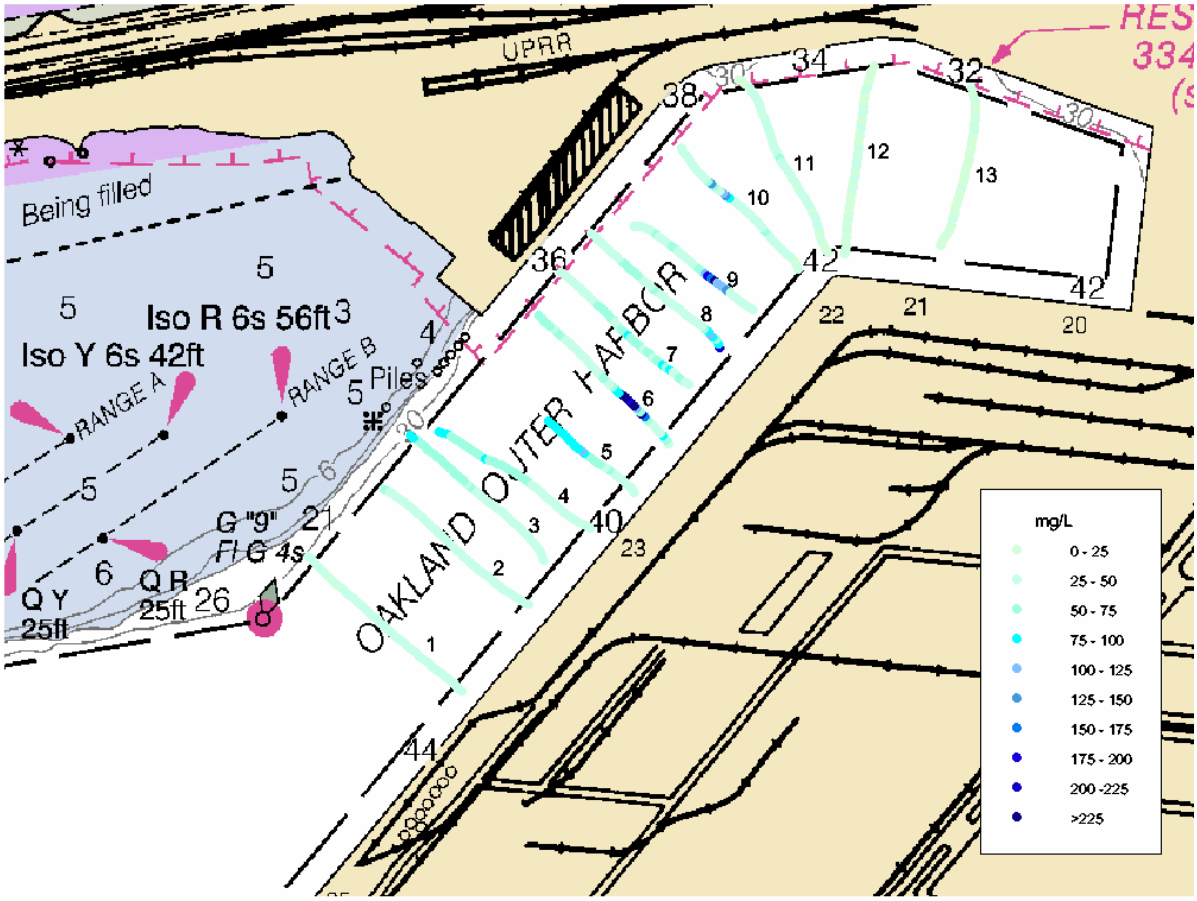

Figure 43. Locations of ADCP Survey ODFC transects in Outer Oakland Harbor during a flooding tide. The dredge was operating adjacent to Transect 5. Depth-averaged acoustic TSS concentration estimates are indicated by color-coded dots.

Transects 1 and 2 (Figures 44 and 45) generally resembled ambient conditions with the exception of a small plume signature (TSS concentrations up to 100 mg/l) on the bottom at the western end of Transect 2. The plume signature expanded over the western half of the water column in Transects 3 and 4 (Figures 46 and 47), with TSS concentrations primarily in the 100 to 150 mg/l range. An intense bottom plume pulse, about 80 m wide and confined below a depth of 8 m, was found on Transect 5 (Figure 48), which lay lateral to the dredge location. A diffuse plume across a broad extent of the channel bottom, with TSS concentrations approaching 125 mg/l, was seen on Transect 6 (Figure 49). Diffuse plume signatures persisted on Transects 7 and 8 (Figures 50 and 51), extending into surface waters. Signs of plume decay were evident on Transects 9 and 10 (Figures 52 and 53), where TSS concentrations remained in the 75 to 100 mg/l range. Total

suspended sediment concentrations continued to decay to ambient levels on Transects 11 and 12 (Figures 54 and 55). Total suspended sediment concentrations throughout the water column on Transect 13 (Figure 56) were very low, generally below 25 mg/l. This was consistent with data for ebb survey ODEC, again indicating that currents were sufficiently weak to allow settlement of fine sediments.

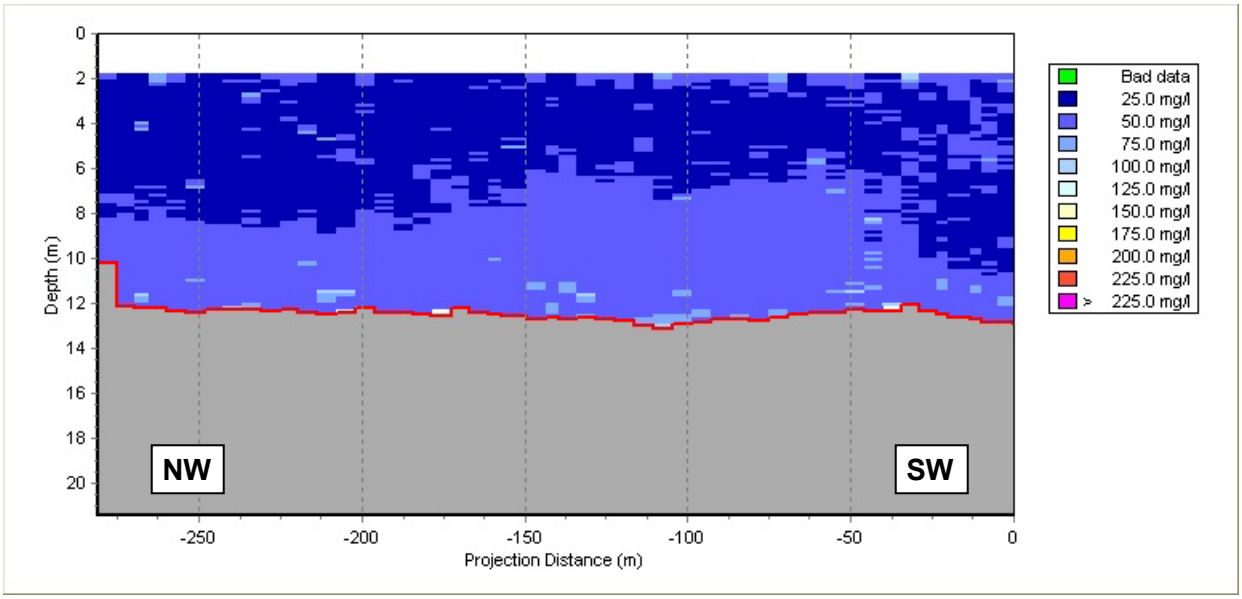

Figure 44. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 1 (approximately 225 m up-current from dredge location) during a flooding tide survey (ODFC) in Outer Oakland Harbor.

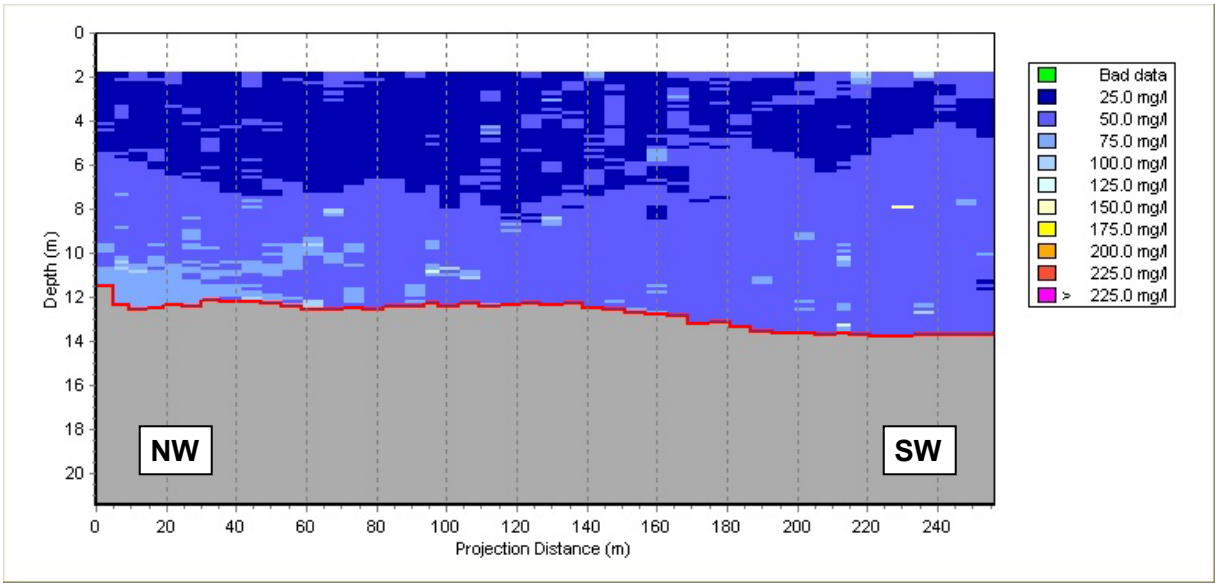

Figure 45. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 2 (approximately 150 m up-current from dredge location) during a flooding tide survey (ODFC) in Outer Oakland Harbor.

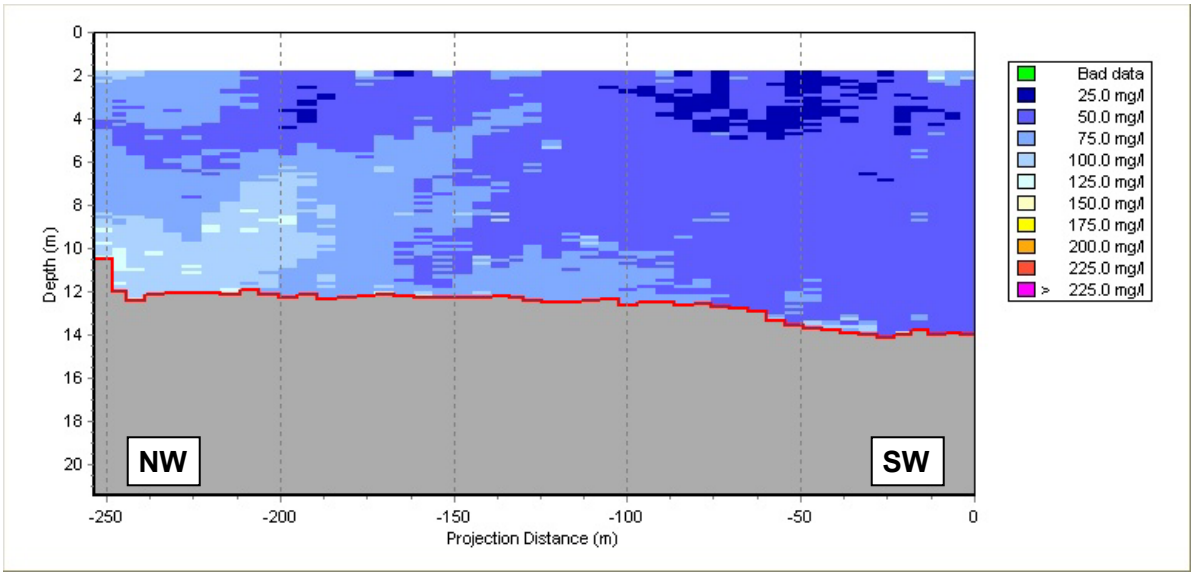

Figure 46. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 3 (approximately 100 m up-current from dredge location) during a flooding tide survey (ODFC) in Outer Oakland Harbor.

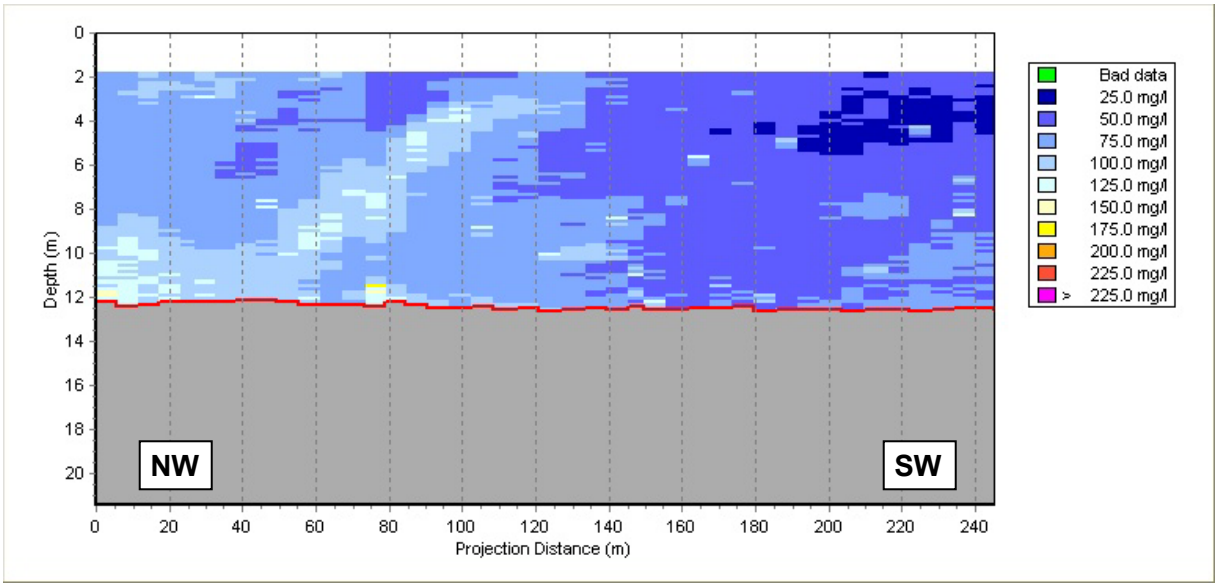

Figure 47. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 4 (approximately 75 m up-current from dredge location) during a flooding tide survey (ODFC) in Outer Oakland Harbor.

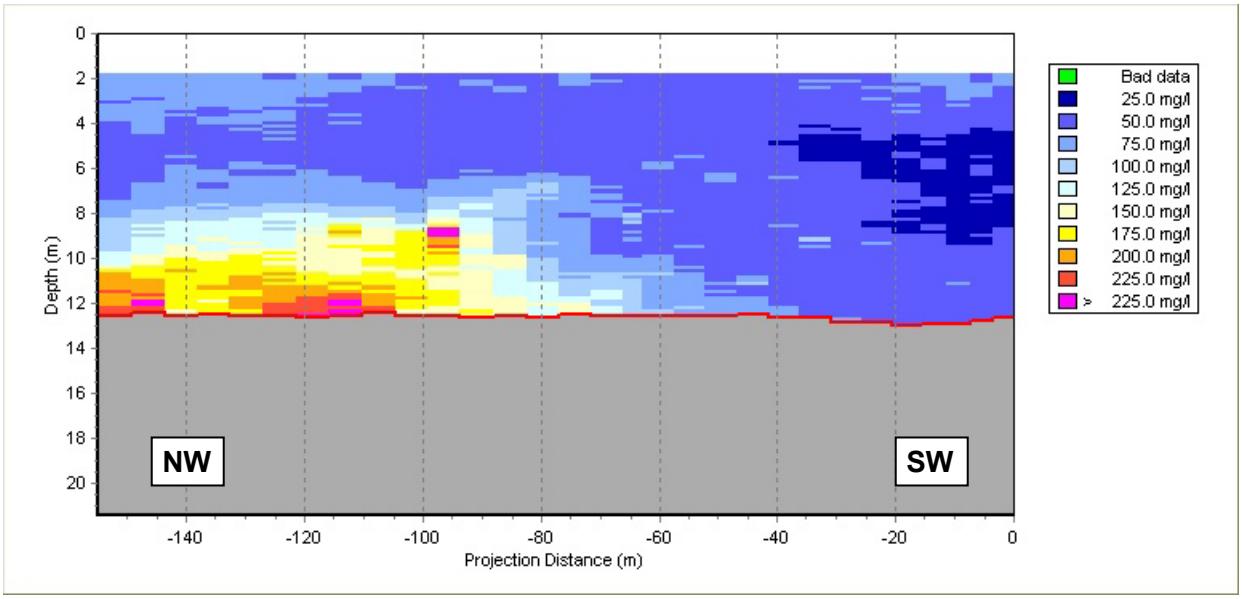

Figure 48. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 5 (adjacent to dredge location) during a flooding tide survey (ODFC) in Outer Oakland Harbor.

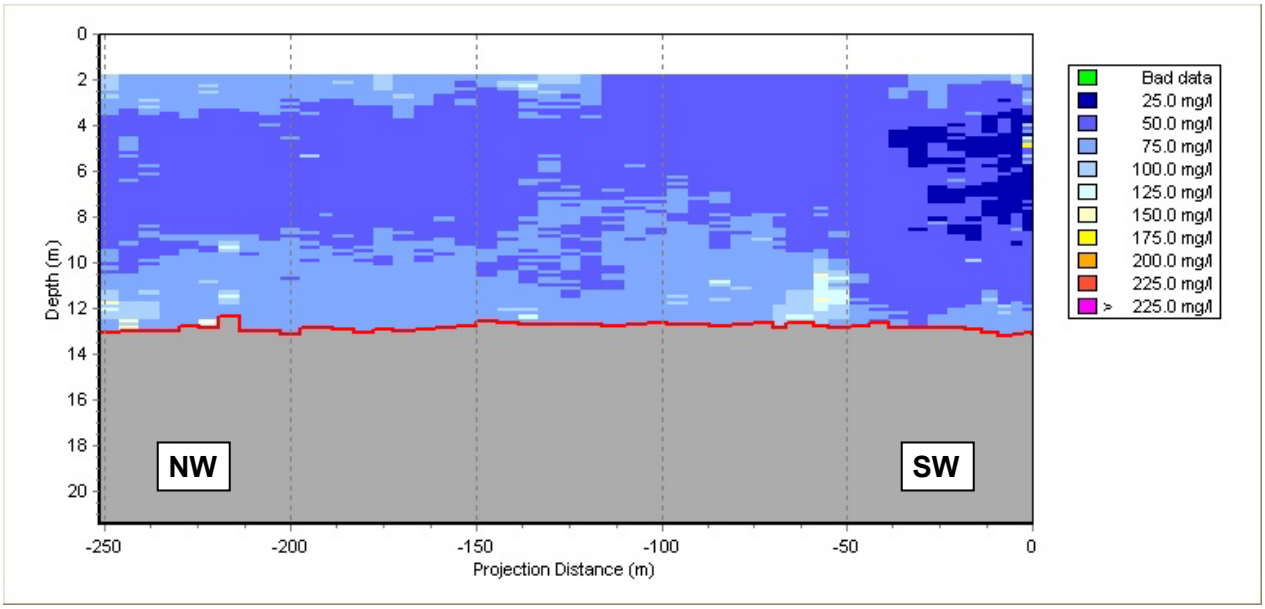

Figure 49. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 6 (approximately 75 m down-current from dredge location) during a flooding tide survey (ODFC) in Outer Oakland Harbor.

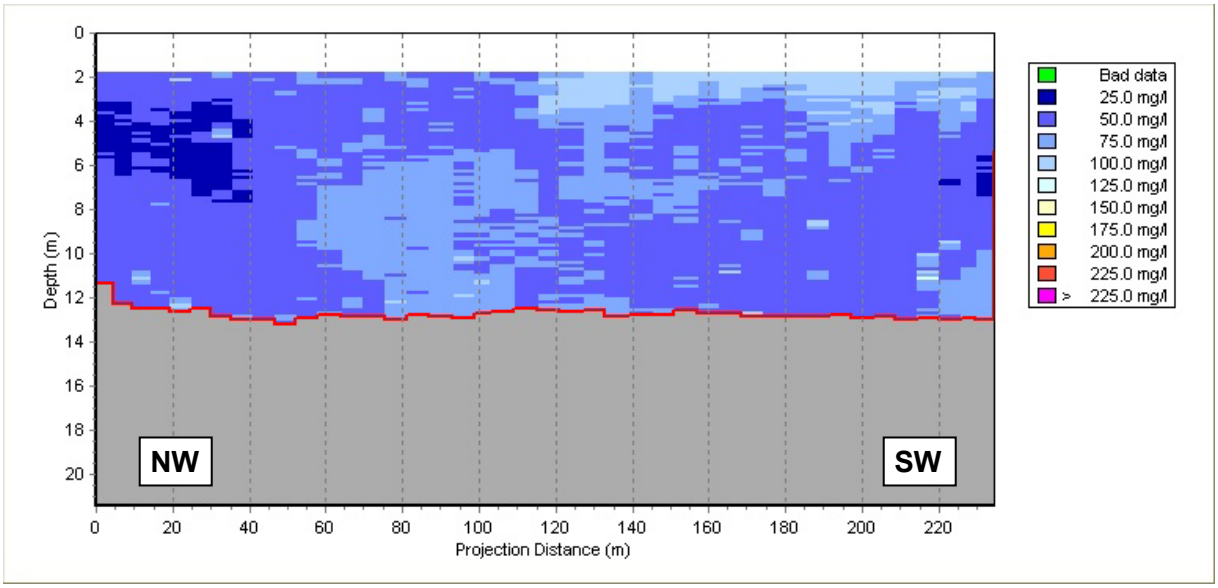

Figure 50. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 7 (approximately 100 m down-current from dredge location) during a flooding tide survey (ODFC) in Outer Oakland Harbor.

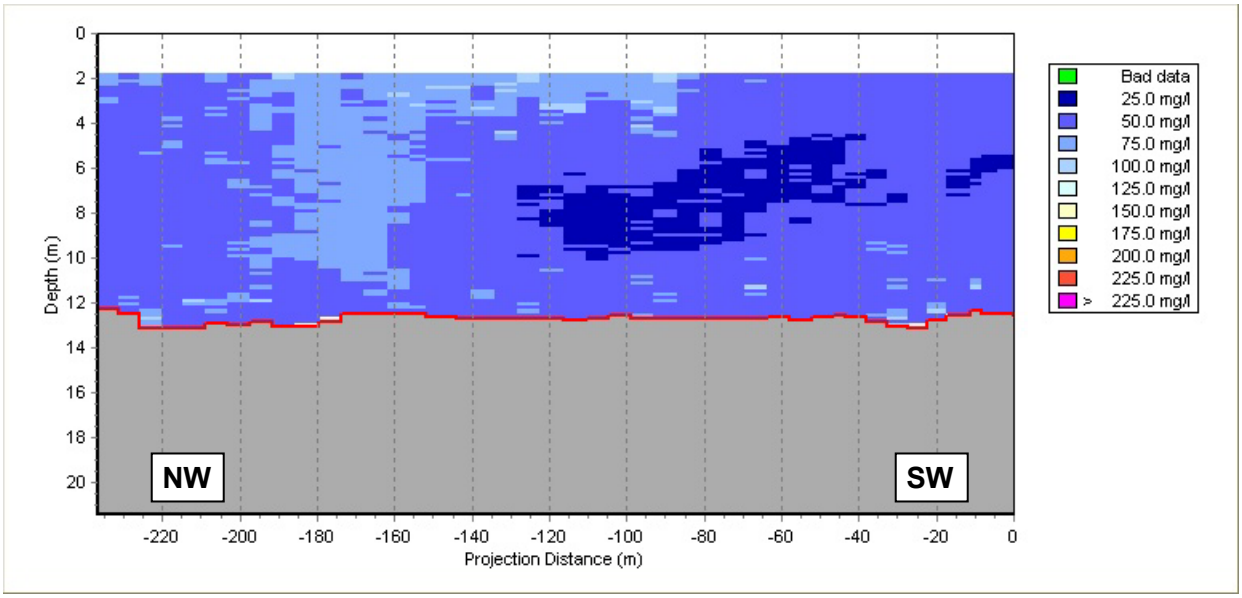

Figure 51. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 8 (approximately 150 m down-current from dredge location) during a flooding tide survey (ODFC) in Outer Oakland Harbor.

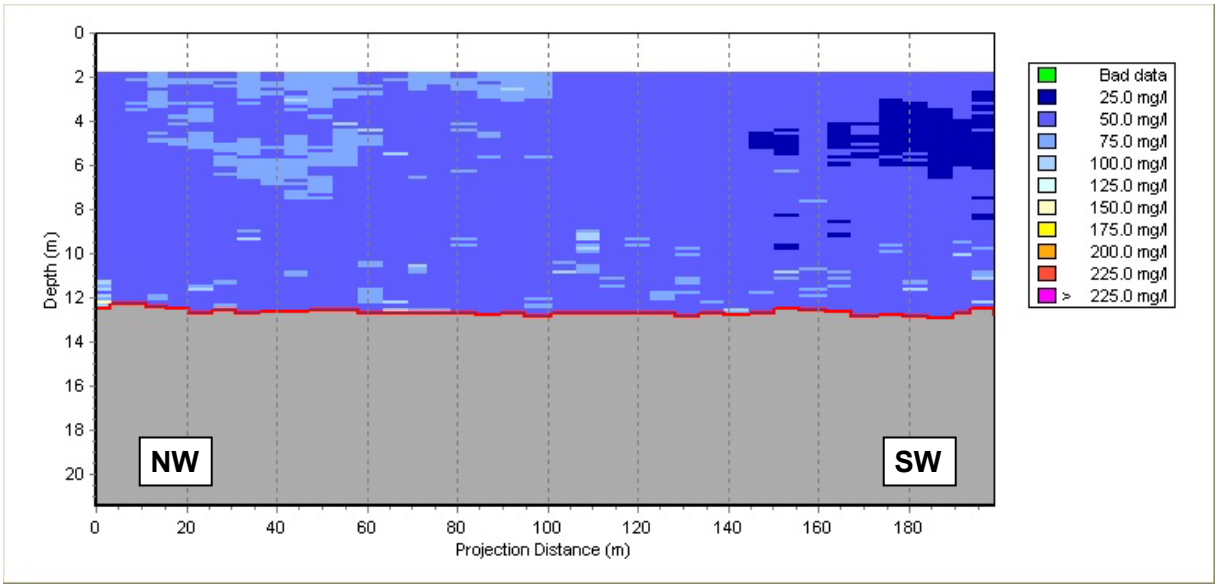

Figure 52. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 9 (approximately 200 m down-current from dredge location) during a flooding tide survey (ODFC) in Outer Oakland Harbor.

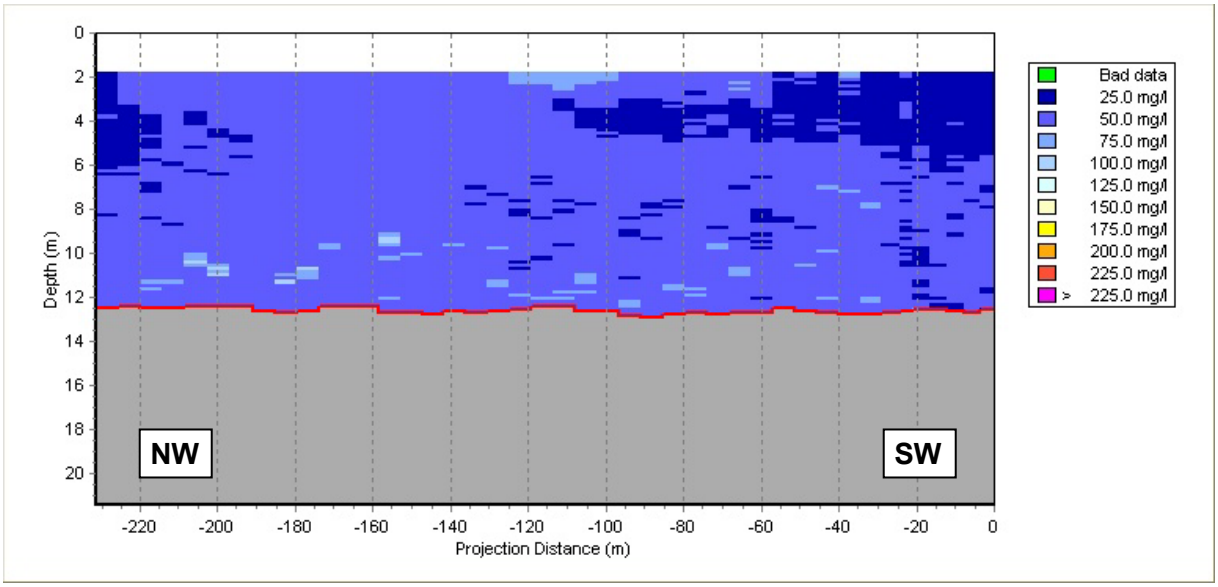

Figure 53. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 10 (approximately 250 m down-current from dredge location) during a flooding tide survey (ODFC) in Outer Oakland Harbor.

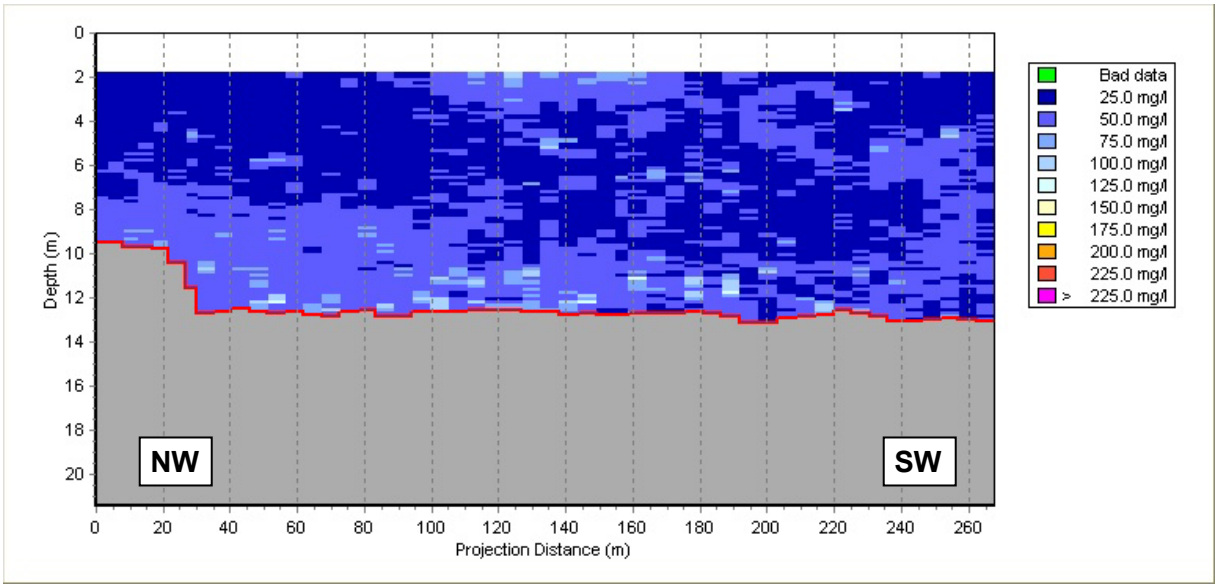

Figure 54. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 11 (approximately 325 m down-current from dredge location) during a flooding tide survey (ODFC) in Outer Oakland Harbor.

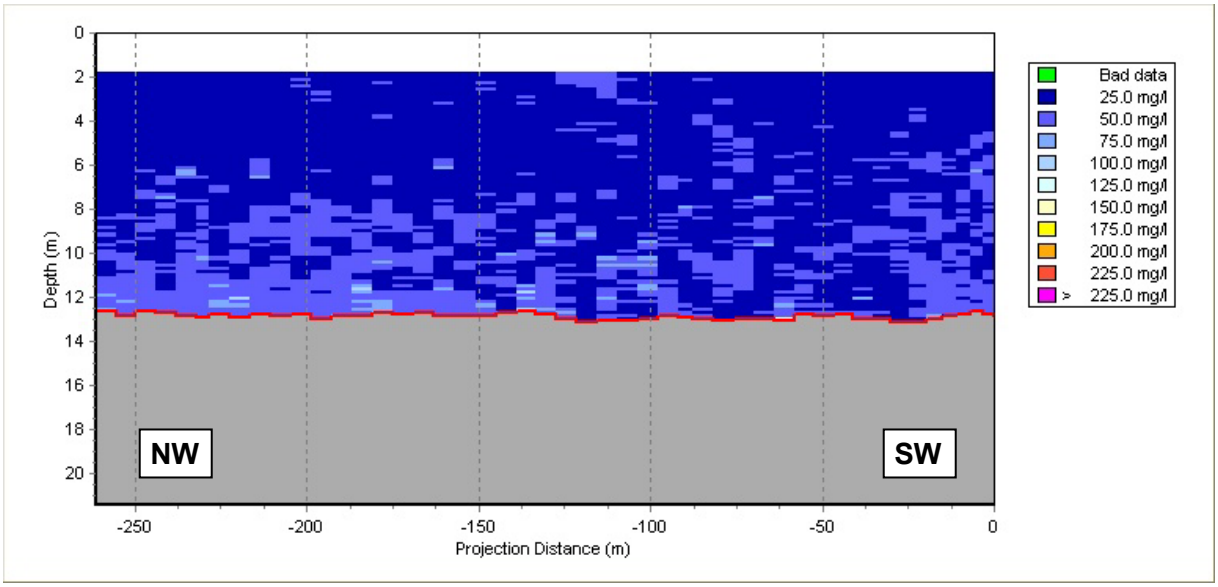

Figure 55. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 12 (approximately 400 m down-current from dredge location) during a flooding tide survey (ODFC) in Outer Oakland Harbor.

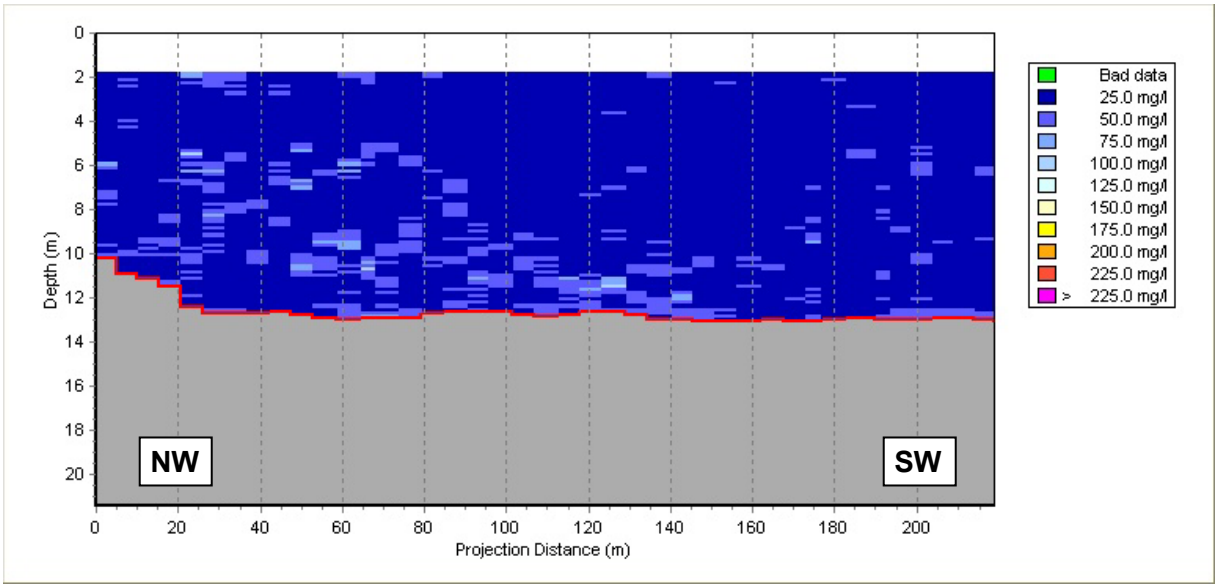

Figure 56. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 13 (approximately 500 m down-current from dredge location) during a flooding tide survey (ODFC) in Outer Oakland Harbor.

An additional during-dredging ADCP survey (ODFD) was conducted during a flooding tide. A plan-view layout of transect locations is given in Figure 57. Vertical cross-sectional profiles of TSS concentration are presented for each transect in Figures 58 through 70. Transect 1 (Figure 58) resembled ambient conditions observed in the other surveys. A small bottom plume acoustic signature, with TSS concentrations up to 150 mg/l, was present on Transect 2 (Figure 59). A broad bottom plume with TSS concentrations in the 100 to 125 mg/l range was evident on Transect 3 (Figure 60). On Transect 4 a very intense gas bubble signature extended upward through the water column, as well as a separate, intense bottom plume with TSS concentrations as high as 225 mg/l dispersing laterally (Figure 61). The surface gas bubble plume persisted on Transect 5, with the separated bottom plume now expanded in mid-depths and decaying to peak TSS concentrations near 175 mg/l (Figure 62). Intense plume signatures dissipated on Transect 6, where remnants of a surface plume remained visible (Figure 63). On Transects 7 and 8 (Figures 64 and 65) diffuse areas of slightly elevated TSS concentrations extended across the bottom below a depth of 8 m. Indications of a surface plume, perhaps with some bubble components, were present. In Figures 66 through 70 a progression was seen in a decay of TSS concentrations and settlement of the diffuse plume lower in the water column from Transects 9 through 13. Waters had lowest TSS concentrations on Transect 13, which lies well into the harbor channel "dead end."

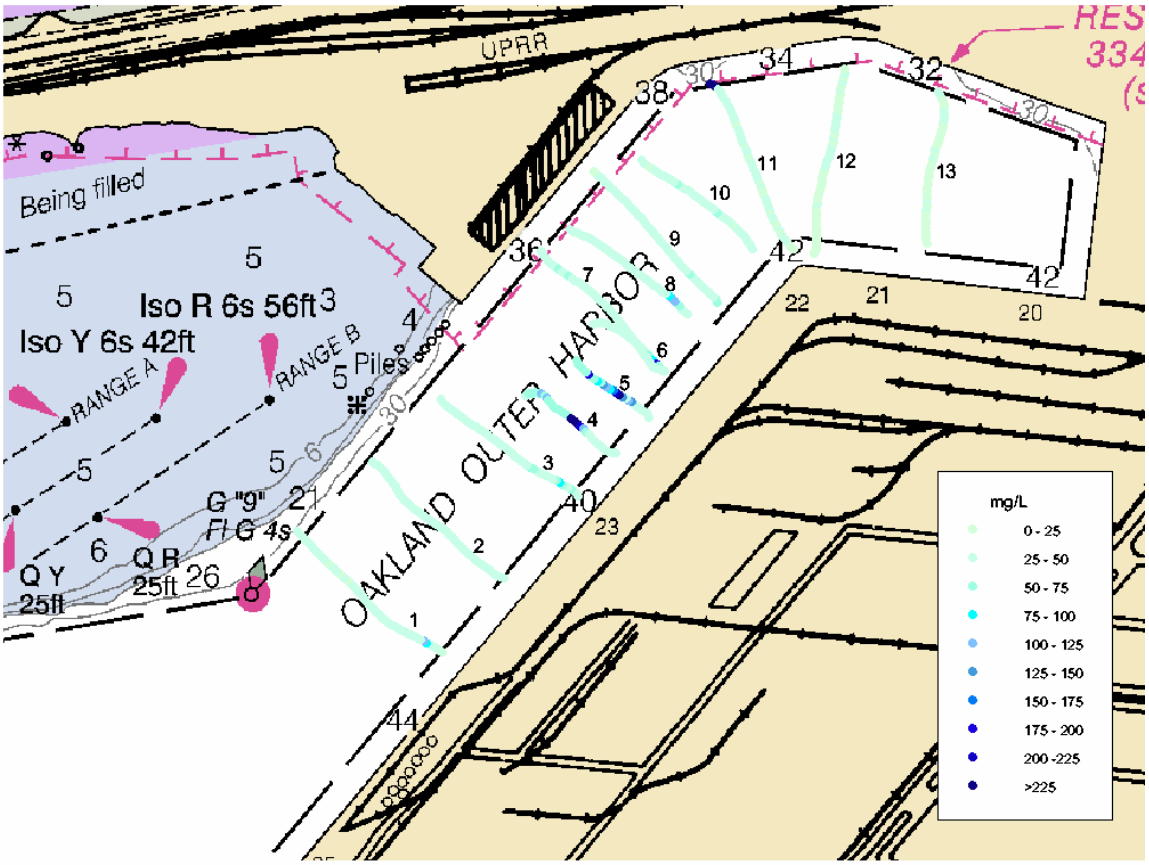

Figure 57. Locations of ADCP Survey ODFD transects in Outer Oakland Harbor during a flooding tide. The dredge was operating adjacent to Transects 4 and 5. Depth-averaged acoustic TSS concentration estimates are indicated by color-coded dots.

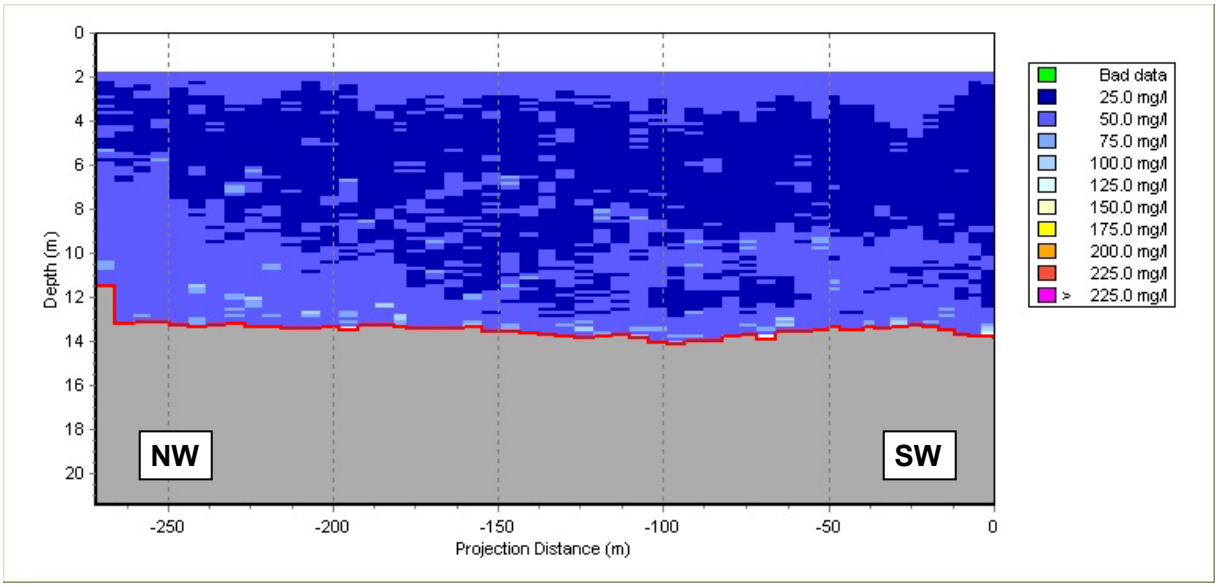

Figure 58. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 1 (approximately 300 m up-current from dredge location) during a flooding tide survey (ODFD) in Outer Oakland Harbor.

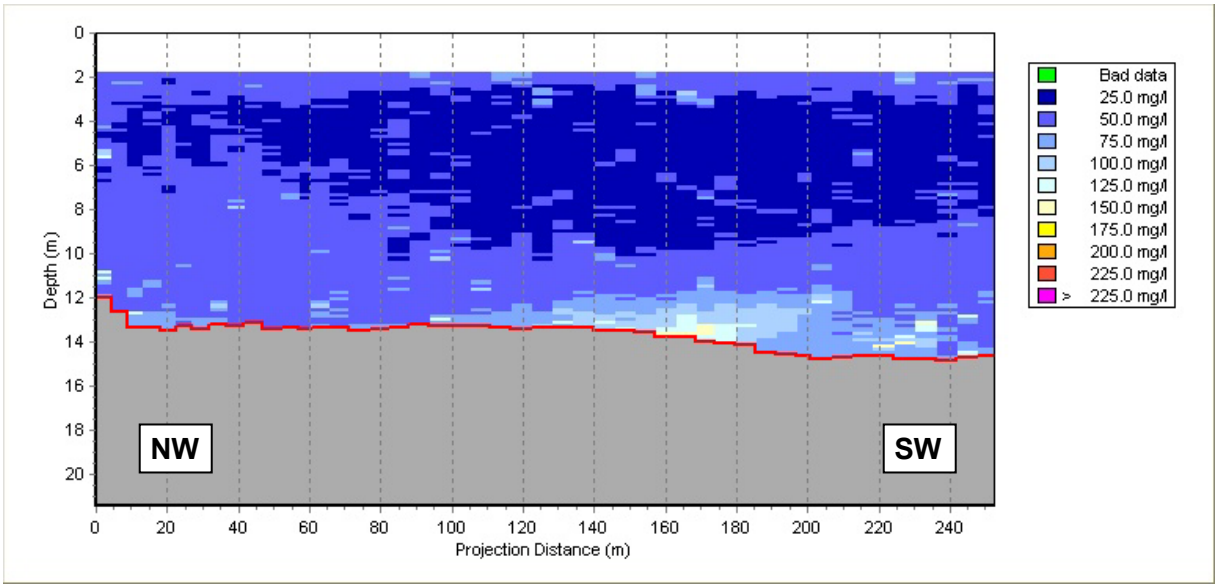

Figure 59. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 2 (approximately 200 m up-current from dredge location) during a flooding tide survey (ODFD) in Outer Oakland Harbor.

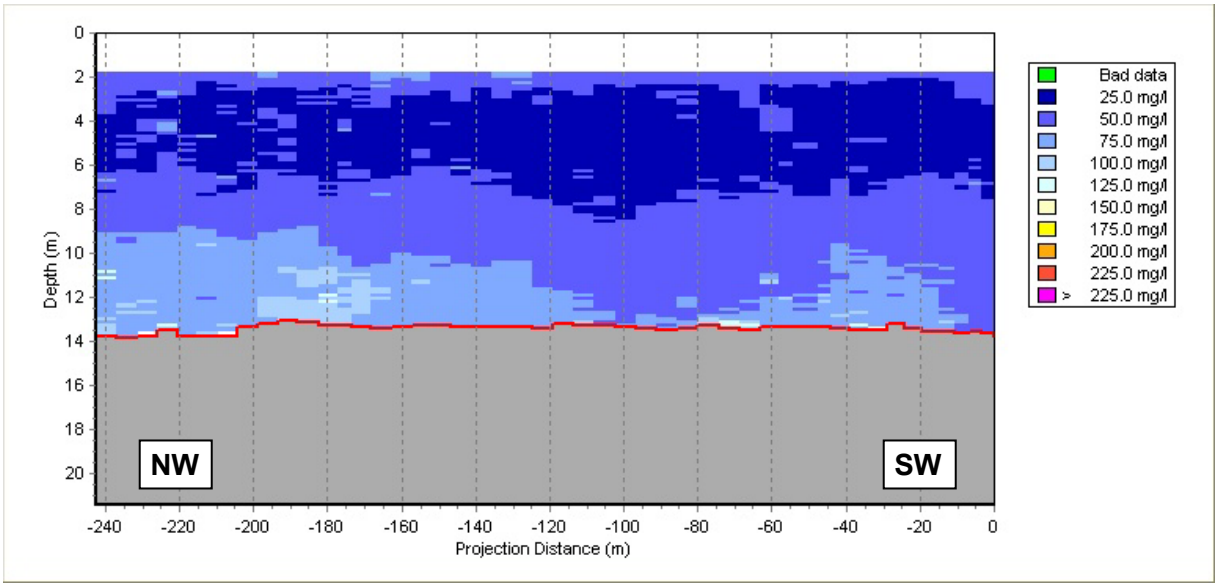

Figure 60. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 3 (approximately 100 m up-current from dredge location) during a flooding tide survey (ODFD) in Outer Oakland Harbor.

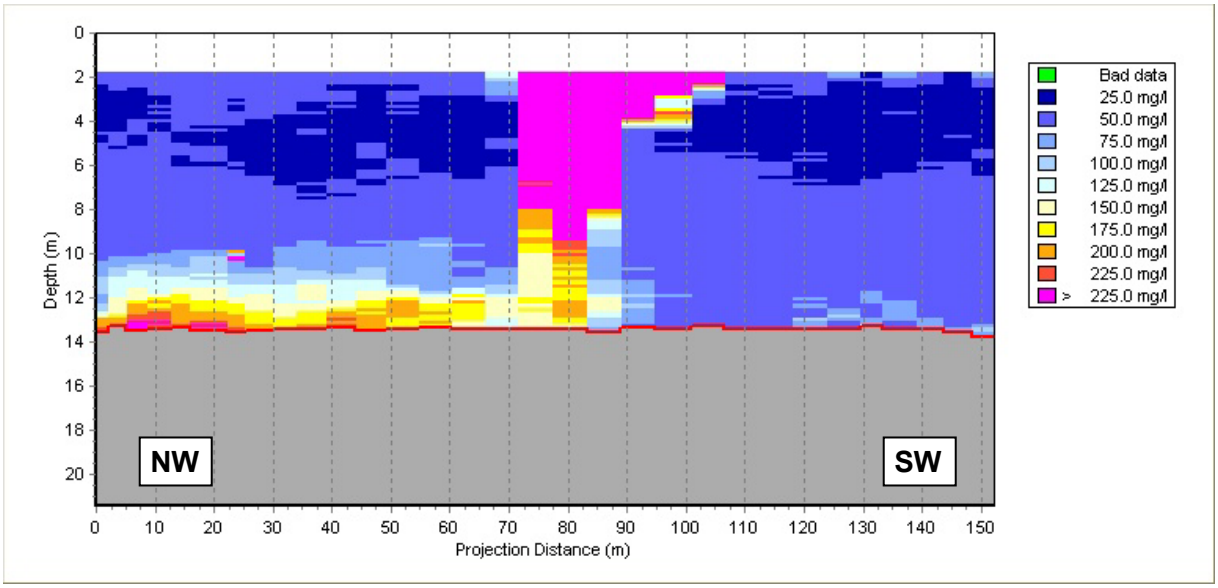

Figure 61. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 4 (approximately 50 m down-current from dredge location) during a flooding tide survey (ODFD) in Outer Oakland Harbor.

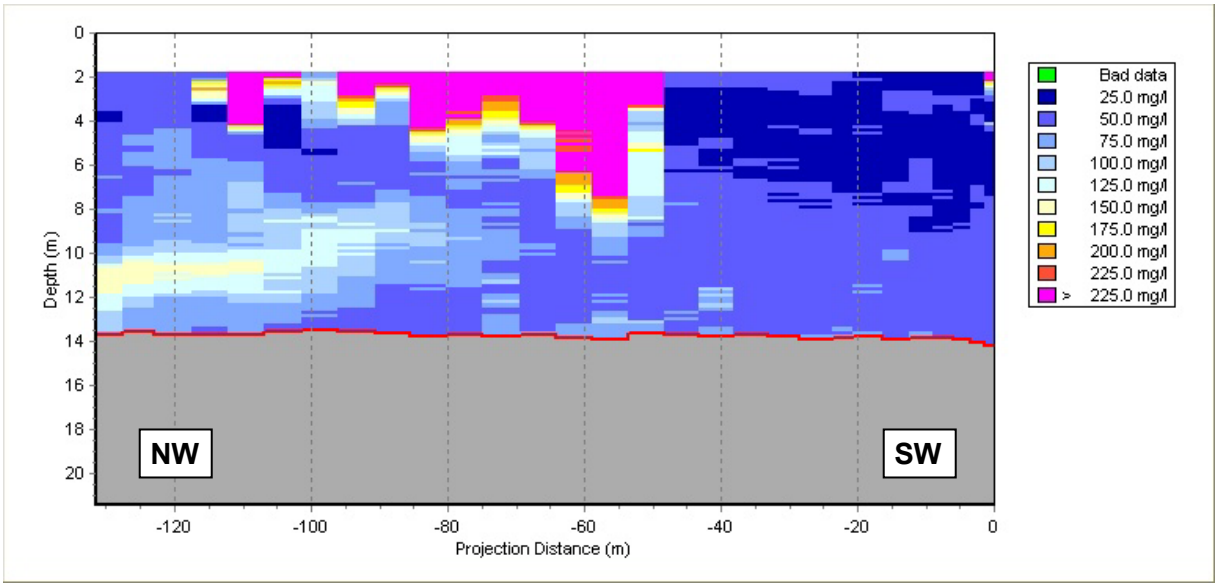

Figure 62. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 5 (adjacent to dredge location) during a flooding tide survey (ODFD) in Outer Oakland Harbor.

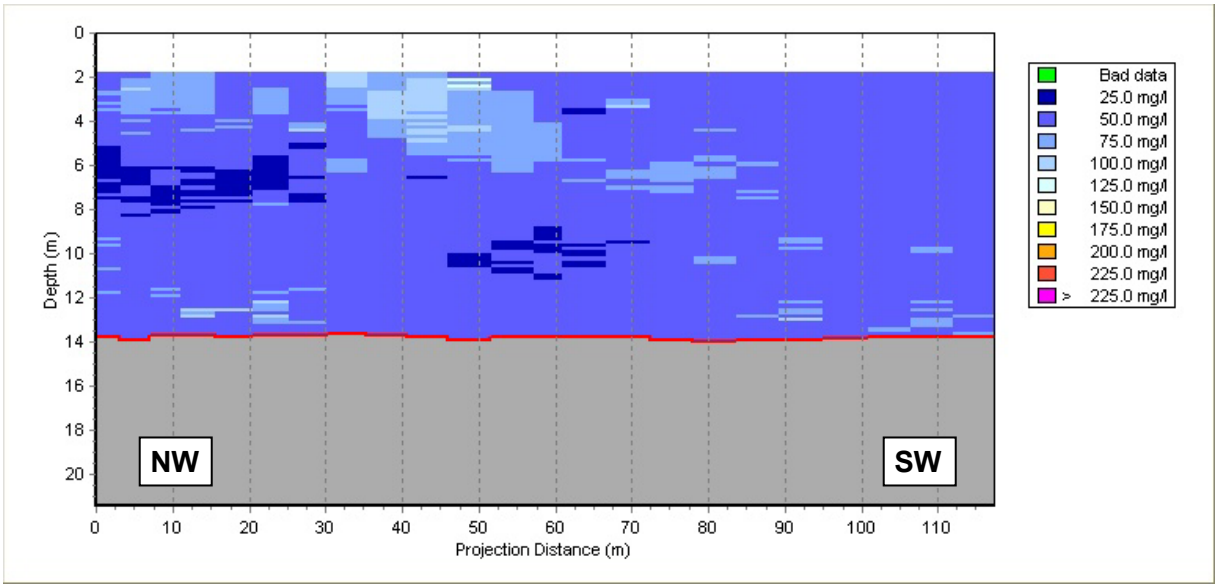

Figure 63. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 6 (approximately 50 m down-current from dredge location) during a flooding tide survey (ODFD) in Outer Oakland Harbor.

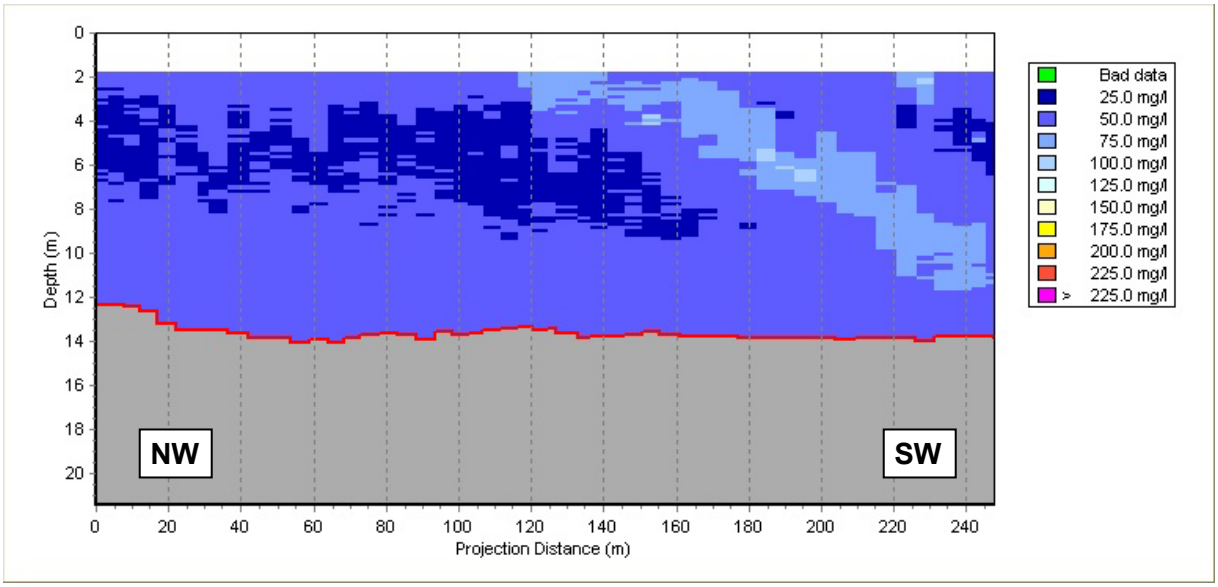

Figure 64. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 7 (approximately 75 m down-current from dredge location) during a flooding tide survey (ODFD) in Outer Oakland Harbor.

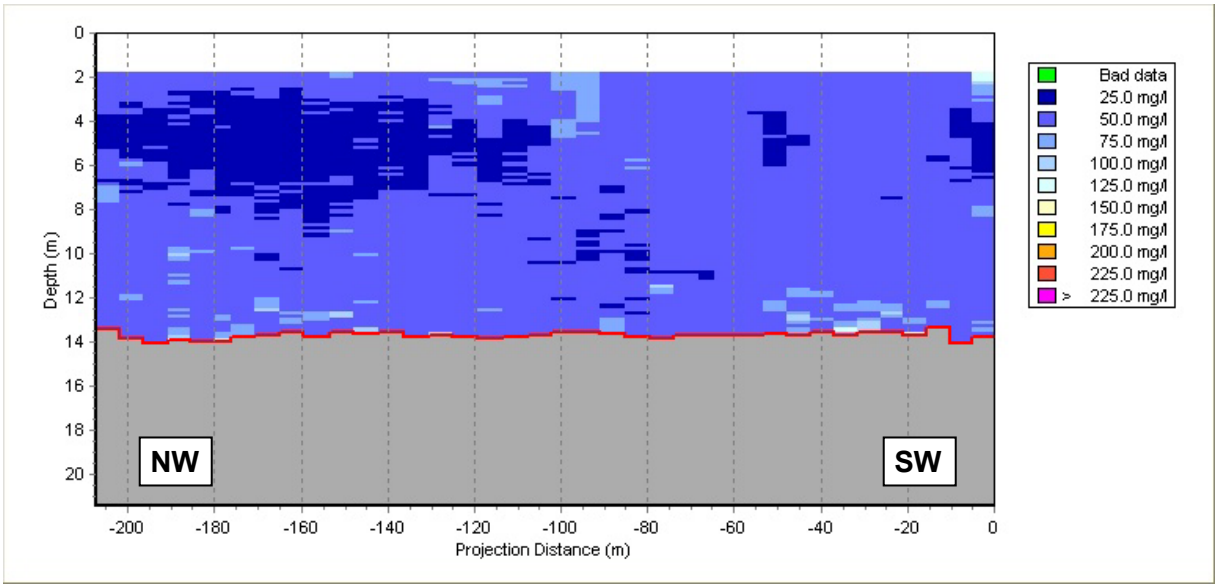

Figure 65. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 8 (approximately 100 m down-current from dredge location) during a flooding tide survey (ODFD) in Outer Oakland Harbor.

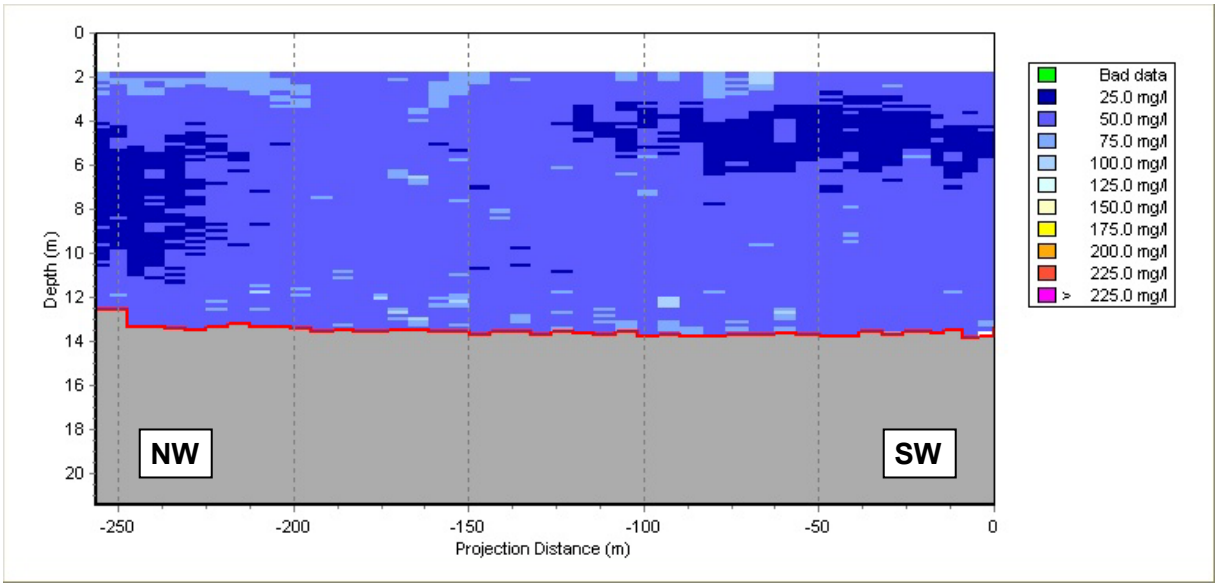

Figure 66. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 9 (approximately 150 m down-current from dredge location) during a flooding tide survey (ODFD) in Outer Oakland Harbor.

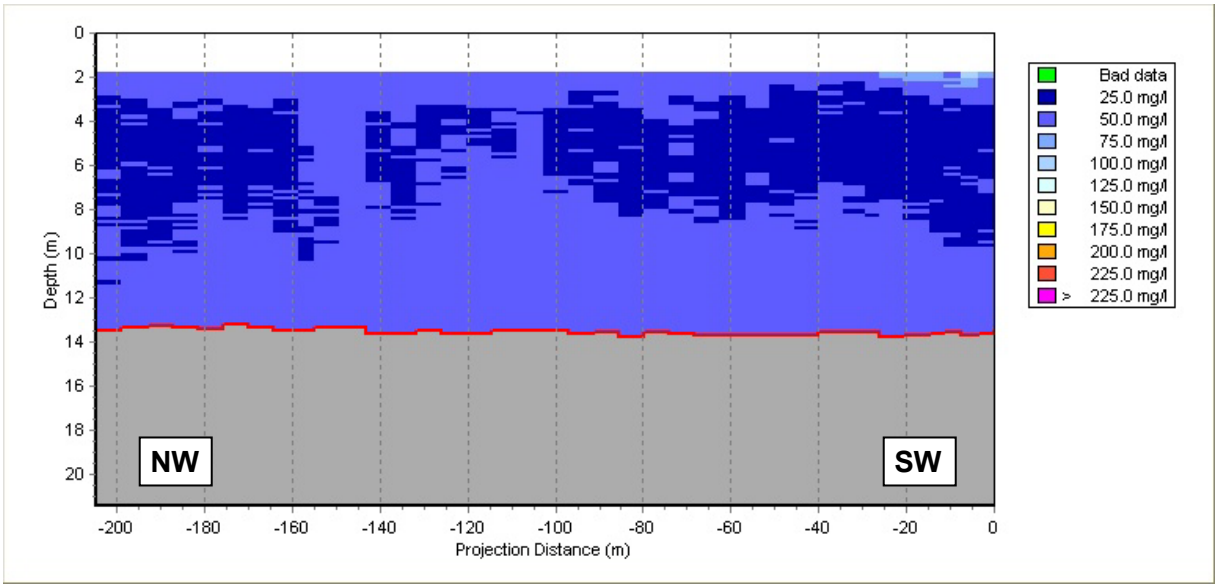

Figure 67. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 10 (approximately 200 m down-current from dredge location) during a flooding tide survey (ODFD) in Outer Oakland Harbor.

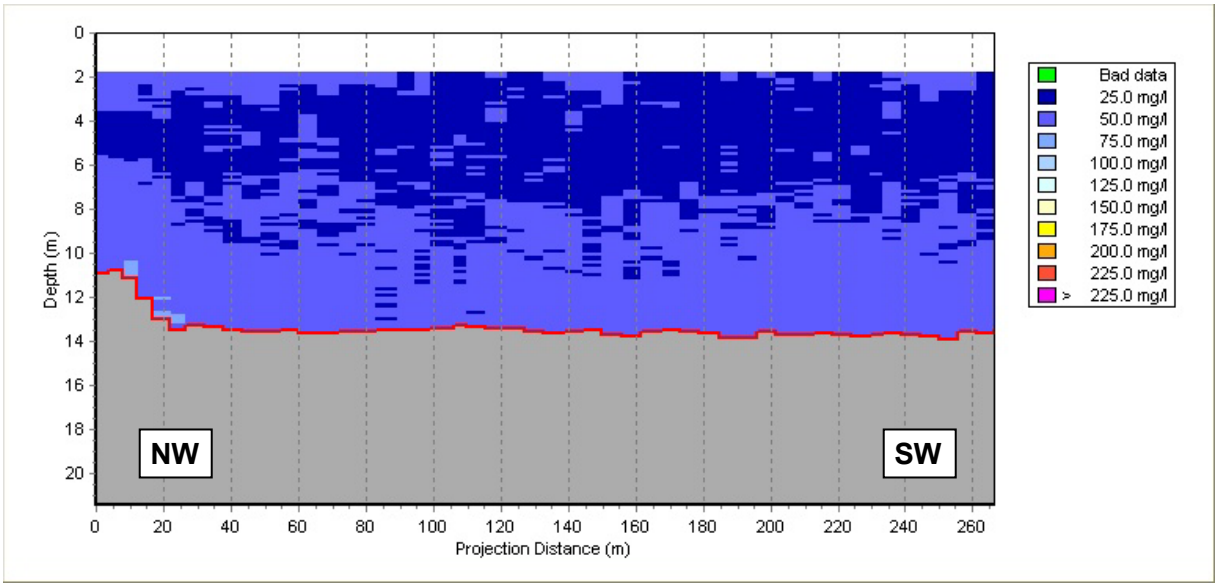

Figure 68. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 11 (approximately 300 m down-current from dredge location) during a flooding tide survey (ODFD) in Outer Oakland Harbor.

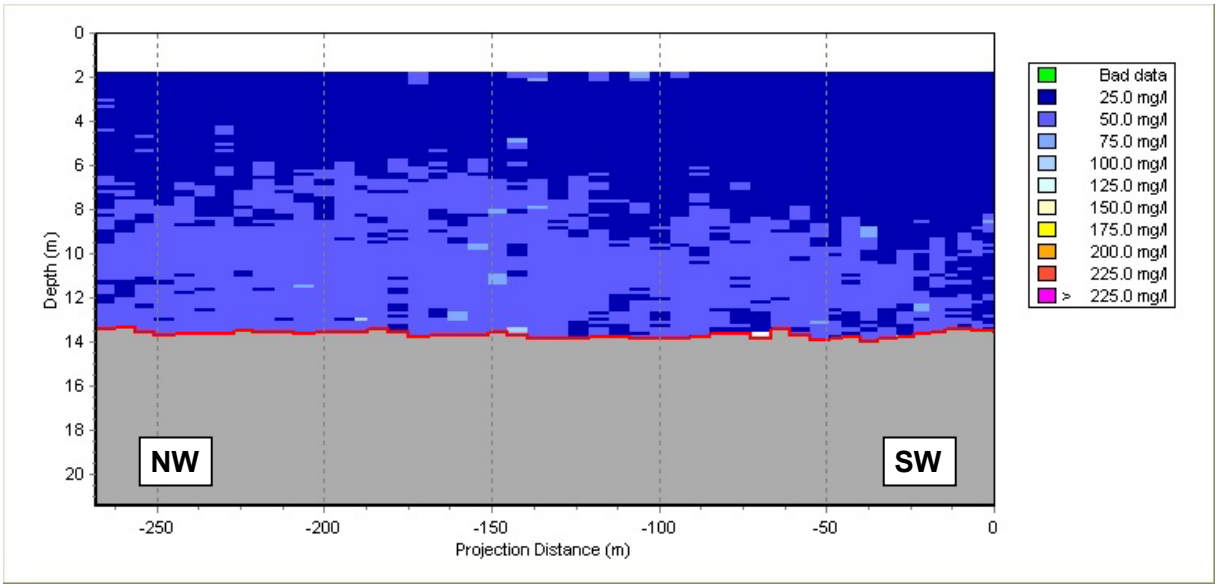

Figure 69. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 12 (approximately 400 m down-current from dredge location) during a flooding tide survey (ODFD) in Outer Oakland Harbor.

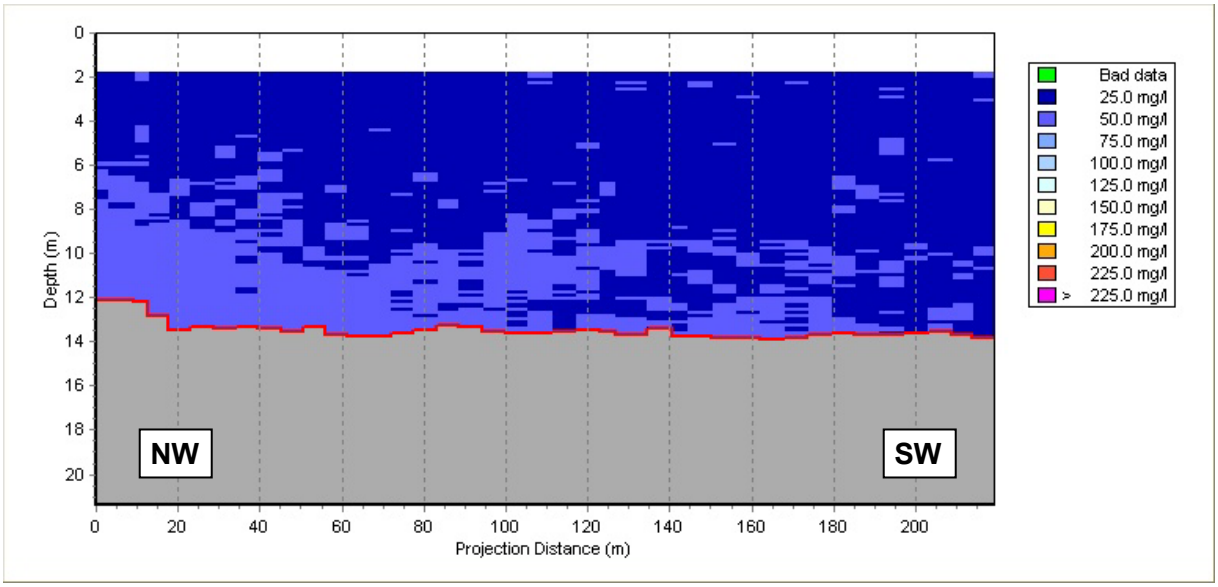

Figure 70. Vertical cross-sectional profile of acoustic estimates of TSS on Transect 13 (approximately 500 m down-current from dredge location) during a flooding tide survey (ODFD) in Outer Oakland Harbor.

Conclusions

ADCP surveys effectively characterized suspended sediment plume structure for bucket dredging operations in the Oakland Outer Harbor navigation channel. Plumes were driven by relatively weak currents during both ebb and flood tidal stages. The closed bucket dredging method used in this project clearly influenced the spatial and temporal dynamics of plumes in the study area. Few indications of surface components of plumes were detected, as the major loss of sediment via re-suspension appeared limited to the lower water column. Plumes were very heterogeneous, consisting of pulses of elevated TSS concentration generated primarily by repetitive bucket impact with the substrate. Net flux of plume-borne sediments appeared to be lateral toward the center of the channel rather than toward open bay waters, even during ebbing tides. The weak current flows, however, did not extend to the innermost portion of the harbor navigation channel. Total suspended sediment concentrations, as observed in ambient and during-dredging surveys, were consistently lowest in the "dead end" area, where flows apparently allowed settlement of fine sediments.

Plumes generated by the dredge in this study were characterized by relatively narrow bands of elevated TSS concentrations that decayed within short distances from the source. In both ebb and flood surveys, acoustic plume signatures were distinct above background TSS concentrations for distances up to 400 m from the source. Plume trajectories were dynamic, extending laterally and both up- and down-current from the operation, as residual plume components from preceding cycles of the bucket persisted in the near-field surrounding the dredge. Total suspended sediment concentrations exceeding 275 mg/l were measured only in immediate proximity to the source. Total suspended sediment concentrations tended to decay fairly rapidly with increasing distance. In general, TSS concentrations above 100 mg/l were distributed in small pockets that primarily flowed just above the bottom, but occasionally dispersed into mid-water depths.

It would be beneficial to conduct comparative ADCP surveys at the study site to characterize plumes generated by a comparably sized conventional bucket. Given the lack of dispersion of plumes demonstrated in this study, some measure of performance in terms of plume reduction by deployment of the closed bucket could be achieved. Likewise, it should be noted that the results of this study are site-specific, i.e. plume dynamics would vary significantly elsewhere in the San Francisco Bay system based on hydrodynamics, geomorphology, and numerous other factors. These data, however, should provide insights into the types and magnitudes of risks to environmental resources posed by dredging at the Outer Oakland Harbor site, and how best to manage those risks.

References

Land, J. M. and Bray, R. N. 2000. Acoustic measurements of suspended solids for monitoring of dredging and dredged material disposal. *Journal of Dredging Engineering* 2(3):1-17.

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Reine, K. J., Clarke, D. G. and Dickerson, C. 2002. Acoustic characterization of suspended sediment plumes resulting from barge overflow. Dredging Operations and Environmental Research Program, Technical Notes Collection (ERDC TN-DOER-E15), U.S. Army Engineer Research and Development Center, Vicksburg, MS. www.wes.army.mil/el/dots/doer

Appendix A. TSS Data

Sample Date	Sample Station	Sample Time	MEC sample No.	Volume Filtered (mL)	Filter Tare Wt (mg)	Filter + Sediment Wt (mg)	TSS (mg/L)	Field Recorded - Transmissivity (%)
8/26/2003	12	18:05	012	500	129.34	138.80	18.92	3.45
8/26/2003	13	18:06	013	500	130.10	145.18	30.16	20.20
8/26/2003	16	18:07	016	500	131.23	138.26	14.06	25.9
8/26/2003	15	18:06	015	500	129.54	138.49	17.90	27.3
8/26/2003	5	17:30	005	500	130.60	146.77	32.34	9.50
8/26/2003	18	18:07	018	250	127.12	129.26	8.56	34.40
8/26/2003	9	17:31	009	250	131.92	146.75	59.32	0.10
8/26/2003	6	17:30	006	250	128.44	134.89	25.80	12.10
8/26/2003	10	17:32	010	250	128.45	163.61	140.64	0.10
8/26/2003	10 Dup			250	129.90	164.66	139.04	0.10
						RPD=	**1.14**	
8/26/2003	8	17:31	008	250	130.68	137.95	29.08	15.90
8/26/2003	17	18:07	017	250	130.65	134.05	13.60	34.50
8/26/2003	3		003	250	128.85	133.10	17.00	2.60
8/26/2003	2		002	250	129.29	136.98	30.76	4.00
8/26/2003	11	17:32	011	250	128.65	136.65	32.00	0.10
8/26/2003	1		001	250	127.50	155.73	112.92	0.47
8/26/2003	14	18:06	014	250	128.69	135.67	27.92	19.87
8/26/2003	7	17:31	007	250	130.41	138.97	34.24	13.1
8/26/2003	20	18:08	020	250	130.99	132.97	7.92	38.34
8/27/2003	21	10:28	021	250	129.8	189.27	237.88	0.01
8/26/2003	19	18:08	019	250	127.46	129.91	9.80	35.03
8/26/2003	19 Dup			250	129.32	131.60	9.12	35.03
						RPD=	**7.19**	
8/27/2003	38	11:31	038	500	129.65	157.75	56.20	22.95
8/27/2003	23	10:29	023	150	128.95	187.29	388.93	0.01
8/27/2003	24	10:29	024	150	130.03	180.85	338.80	0.01
8/27/2003	25	10:30	025	150	128.86	173.11	295.00	0.04
8/27/2003	26	10:30	026	150	129.54	164.89	235.67	0.01
8/27/2003	27	10:31	027	150	130.58	163.37	218.60	0.04
8/27/2003	22	10:29	022	150	129.49	183.88	362.60	0.01
8/27/2003	28	10:31	028	150	131.25	153.76	150.07	0.06
8/27/2003	29	10:31	029	250	128.81	161.25	129.76	0.16
8/27/2003	29 Dup			250	126.8	157.55	123.00	0.16
						RPD=	**5.35**	
8/27/2003	30	11:28	030	350	130.62	144.50	39.66	28.73
8/27/2003	32	11:29	032	500	130.19	135.69	11.00	29.65
8/27/2003	35	11:30	035	500	129.42	134.68	10.52	16.51
8/27/2003	34	11:30	034	500	129.54	134.71	10.34	25.6
8/27/2003	33	11:29	033	500	128.97	135.7	13.46	28.3
8/27/2003	36	11:30	036	250	130.39	133.72	13.32	11.68
8/27/2003	37	11:31	037	500	128.19	140.05	23.72	15.55
8/27/2003	39	14:59	039	500	133.72	139.72	12.00	27.73
8/27/2003	41	15:01	041	500	130.30	135.34	10.08	29.41
8/27/2003	42	15:01	042	500	128.90	133.37	8.94	34.16
8/27/2003	43	15:27	043	250	129.77	167.79	152.08	0.01
8/27/2003	43 Dup			250	127.99	166.00	152.04	0.01
						RPD=	**0.03**	
8/27/2003	44	15:27	044	250	128.96	176.31	189.40	0.01
8/27/2003	45	15:28	045	250	128.49	171.56	172.28	0.01
8/27/2003	41	15:01	041	500	128.30	164.59	72.58	29.41
8/27/2003	46	15:28	046	250	130.50	174.75	177.00	0.01
8/27/2003	48	15:29	048	250	130.14	161.13	123.96	0.13
8/27/2003	49	15:29	049	250	129.56	147.50	71.76	17.78
8/27/2003	50	15:29	050	250	128.14	135.81	30.68	9.64

Sample Date	Sample Station	Sample Time	MEC sample No.	Volume Filtered (mL)	Filter Tare Wt (mg)	Filter + Sediment Wt (mg)	TSS (mg/L)	Field Recorded - Transmissivity (%)
8/27/2003	50 Dup			250	131.36	138.40	28.16	9.64
						RPD=	**8.57**	
8/27/2003	51	15:30	051	250	129.01	135.83	27.28	8.88
8/27/2003	47	15:28	047	250	128.79	165.85	148.24	0.23
8/28/2003	52	9:31	052	250	127.36	130.53	12.68	25.49
8/28/2003	54	9:32	054	250	128.38	132.03	14.60	22.22
8/28/2003	57	9:33	057	250	127.53	130.03	10.00	28.35
8/28/2003	58	9:33	058	250	128.76	131.38	10.48	28.28
8/28/2003	59	9:34	059	250	128.89	131.32	9.72	29.29
8/28/2003	60	9:34	060	250	128.34	131.27	11.72	26.93
8/28/2003	61	11:56	061	250	126.48	128.89	9.64	34.5
8/28/2003	61 Dup			250	126.43	128.75	9.28	34.5
						RPD=	**3.81**	
8/28/2003	62	11:56	062	350	127.03	129.54	7.17	36.68
8/28/2003	63	11:57	063	350	128.50	131.39	8.26	39.42
8/28/2003	65	11:57	065	250	128.08	129.74	6.64	43.19
8/28/2003	66	11:58	066	350	130.41	132.62	6.31	42.73