ERDC/EL TR-15-5

US Army Corps of Engineers®
Engineer Research and Development Center

ERDC
INNOVATIVE SOLUTIONS for a safer, better world

Dredging Operations Technical Support Program

Characterization of Suspended Sediment Plumes Resulting from Barge Decanting in San Francisco Bay

Kevin J. Reine and Paul R. Schroeder

June 2015

Environmental Laboratory

Dredging Operations Technical Support Program

ERDC/EL TR-15-5
June 2015

Characterization of Suspended Sediment Plumes Resulting from Barge Decanting in San Francisco Bay

Kevin J. Reine and Paul R. Schroeder

Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

Abstract

The San Francisco Bay Regional Water Quality Control Board (SFRWQB) and the U.S. Environmental Protection Agency (USEPA) are seeking to prohibit barge decanting during dredging operations. The agencies cite environmental concerns associated with the release of suspended sediments as the primary justification for banning the barge decanting activities. Since approximately 40% to 70% of the volume placed in the scow is water, this will create budgetary cost overruns for future dredging projects. Transporting this volume of water (124 miles round trip) rather than sediment would significantly impact the efficiency and cost of conducting dredging. Projected cost increases without decanting could be more than 40%. To assess potential impacts from barge decanting, acoustic surveys using a 600 kHz acoustic doppler current profiler (ADCP) were conducted to (1) determine the total suspended solids (TSS) concentration above ambient for plumes produced by both barge decanting and buckets associated with mechanical dredging; (2) determine the TSS of the supernatant water during barge loading, after the settling period and during the decanting process as water passes through the standpipe; and (3) determine the percent of dry mass of sediment loss back to the water column as a result of decanting. Results indicated that no distinct, identifiable plume signature associated with barge decanting was detected by the ADCP. Based on the calculations of TSS from the supernatant discharge, decanting would increase losses by no more than 0.1%. Decanting would, however, increase the effective loading capacity by as much as 50%.

Contents

Figures and Tables

Figures

Tables

Preface

This study was a joint effort between the U.S. Army Engineer Research and Development Center (ERDC) and the U.S. Army Corps of Engineers San Francisco District (SPN), under the Dredging Operations and Technical Support (DOTS) Program.

Principal Investigators for this study were Kevin J. Reine of the Wetlands and Coastal Ecology Branch (CEERD-EEW) of the Ecosystem Evaluation and Engineering Division (CEERD-EE), and Dr. Paul Schroeder, Environmental Engineering Branch (CEERD-EPE), ERDC-Environmental Laboratory (EL). Funding was provided by SPN and by the DOTS Program, which is managed by Cynthia Banks. At the time of publication, Patricia Tuminello was Chief, CEERD-EEW; Mark Farr was Chief, CEERD-EE; Dr. Jack Davis was the Deputy Director of ERDC-EL; and Dr. Beth Fleming was the Director of ERDC-EL.

The authors wish to thank Richard Hudson of the ERDC-EL for processing sediment samples. The authors also thank Captain Ray Santos of the Sausalito Site Office, SPN. Sincere appreciation is also extended to Edward Keller, Cynthia Fowler, and Kevin McCullough, SPN, for technical and logistical support. The authors wish to thank Dr. Douglas Clarke, formerly of the ERDC-EL; Edward Keller; and Jessica Burton Evans for a timely review of this paper.

LTC John T. Tucker III was Acting Commander of ERDC, and Dr. Jeffrey P. Holland was Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	0.0254	meters
knots	0.5144444	meters per second
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
yards	0.9144	meters

Acronyms and Abbreviations

ADCP	Acoustic Doppler Current Profiler
CDF	Confined Disposal Facility
cm/sec	Centimeters per Second
cyd	Cubic Yards
DGPS	Differential Global Positioning Satellite
DOTS	Dredging Operations and Technical Support Program
EPA	Environmental Protection Agency
ERDC	Engineer Research and Development Center
ft	Foot
g/L	Grams per Liter
GSD	Grain Size Distribution
m	Meters
m^3	Cubic Meters
mg/L	Milligrams per Liter
NOAA	National Oceanic and Atmospheric Administration
SAV	Submerged Aquatic Vegetation
SFDODS	San Francisco Deep Ocean Disposal Site
SFRWQB	San Francisco Bay Regional Water Quality Board
TSHD	Trailing Suction Hopper Dredge
TSS	Total Suspended Solids
USACE	United States Army Corps of Engineers
yd^3	Cubic Yards

Executive Summary

Problem: The San Francisco Bay Regional Water Quality Control Board (SFRWQB) and the U.S Environmental Protection Agency (USEPA) are seeking to prohibit barge decanting during dredging operations. The agencies cite environmental concerns associated with release of suspended sediments as the primary justification for taking this action. Since approximately 40% to 70% of the volume placed in the scow is water, this will create budgetary cost overruns for future projects. Transporting this volume of water would significantly impact the efficiency and cost of conducting dredging, due to the burden of transporting water rather than sediment. Projected costs without decanting could increase more than 40%.

Objectives: The objectives of this study were to (1) determine total suspended solids (TSS) concentration above ambient for plumes produced by both barge decanting and buckets associated with mechanical dredging, (2) determine TSS of the supernatant water during barge loading, after the settling period and during the decanting process as water passes through the standpipe, and (3) determine the percent of dry mass of sediment loss back to the water column as a result of decanting.

Approach: The approach of this study entailed (1) using an RDI Acoustic 600 kHz Mariner Workhorse® acoustic doppler current profiler (ADCP) to map the spatial and temporal extent of plumes generated during the decanting process, (2) analyzing ADCP data using the Sediview Method, which derives estimates of TSS concentrations by converting backscatter data to TSS, (3) collecting water samples for gravimetric analysis for calibration purposes and for determining sediment loss, (4) calculating sediment flux by subtracting background flux from plume results during both decanting and non-decanting periods, (5) determining whether barge decanting increases TSS concentrations when compared to dredging without decanting, and (6) predicting/calculating dry mass loss and conducting settling analysis of water samples collected from the supernatant.

Results: No distinct, identifiable plume signature associated with barge decanting was detected by the ADCP, it also was not visually observed at the surface by field crews. Plumes generated by sediment excavation, which

would be several orders of magnitude greater than plumes expected from decanting, were short-lived, rapidly decaying features with low to moderate TSS concentrations. The highest concentrations were found at distances of no more than 125 m from the point source. Only traces of the plume were detected to distances of less than 300 m and only along the extreme channel bottom (lower than 1 m). Decanting discharges would increase sediment loss by no more than 0.1% (compared to sediment loss without decanting). Decanting would increase capacity by 50%. These are conservative predictions; actual loss rates may be less than half of these rates.

Conclusions: The barge decanting process as conducted at Richmond, CA did not inject sufficient quantities of suspended sediment into the water column to be detectable beyond the confines of the dredge and barge, and — if merged with the bucket plume — did not appreciably increase the TSS concentrations evident in that plume. TSS concentrations generated during sediment excavation were less than 200 mg/L, which would be insufficient to have negative/lethal impacts on fishes in the vicinity of the dredging operation. Assuming that mobile or drifting organisms were present, exposure to suspended sediments would be very short term, as plumes decayed to nearly background levels in 10 to 15 minutes after the dredge stopped production. With regard to submerged aquatic vegetation (SAV) (such as eelgrass), TSS plumes based on USACE DREDGE dispersion model results would rapidly disperse to below 5 mg/L in 50 meters and below 2 mg/L in 100 meters. Ambient TSS concentrations in the study area were generally less than 20 mg/L. SAV occurs outside of the channel so no exposure would occur if the plume remained confined to the navigation channel. No evidence of plume transport out of the confines of the channel side slopes was observed.

1 Introduction

The San Francisco Regional Water Quality Boards (SFRWQB) and the U.S. Environmental Protection Agency (USEPA) have prohibited the decanting of supernatant water during navigation dredging operations. These regulations will result in a significant cost increase to navigation dredging projects within the Bay. Decant waters can produce as much as 50% of the total volume of dredged material placed in an attending scow. For example, a 3,000 cyd scow (filled to 80% capacity = 2,400 cyd) would hold only 1,200 cyd of dredged sediment and 1,200 cyd of water if decanting is not permitted. Typically, a barge filled to the 80% capacity level after decanting would hold 2,400 cyd of sediment ready for transport as a single load to the offshore placement site. If decanting is not allowed, then two barge loads would be required to transport the equivalent amount of sediment. The additional fuel usage associated with the increased number of round trips required to complete the project will have negative effects on air quality due to increased emissions. Transporting this volume of water (2,100 cyd) will significantly add to both the efficiency (e.g., duration of the dredging project) and costs, given the distance (124 miles round trip) to the offshore placement site (SFDODS). While overflow typically associated with hopper dredging has been prohibited within the Bay for some time, these agencies and the U.S. Army Corps of Engineers have produced conflicting dredging specifications regarding the use or non-use of decanting protocols. For example, Section 35 20 23, Paragraph 3.2.6.1.1 of the Unified Facilities Guide Specifications states that overflow is not allowed from scows, barges, or pipelines, etc., during dredging operations, except for water released through the internal standpipes on scows that are configured with this equipment. In 2012, the term overflow prohibition was expanded by regulators to include all decanting of water discharge, to include scows used in mechanical dredging projects. It is estimated that in the absence of decanting, navigation projects would incur a 40% increase in total costs. Additionally, large volumes of water transported in the scow will be subjected to “topping” the side of the barge due to offshore wind-driven wave action. This, in turn, could result in discharge of sediment-laden water into protected offshore areas. The current study addresses one type of discharge methodology (Richmond Protocol) to differentiate between overflow and decanting methodologies by determining whether the decant water would significantly increase total suspended solids (TSS) at the dredging site. If the decant water does increase TSS, secondary goals of the study are to examine the spatial and temporal extent of the generated plumes and determine the dry mass loss of sediment return back to the water column.

2 Background

Throughout all dredging and throughout some dredged material disposal operations (with a possible exception being the deposition into a confined disposal facility (CDF)), some sediment is resuspended into the water column. Suspended sediments and their subsequent deposition are sources of concern to fishery resource agencies due to potential impacts on sensitive species and their habitats. A review of suspended sediment effects in coastal habitats with an emphasis on potential impacts of dredging operations can be found in Wilber and Clarke (2001). For bucket dredges, sediment resuspension comes from various sources, including contact with and bucket closure in the seabed, sediment washed from the exposed surfaces of the bucket as it moves through the water column, spillage of sediment-laden water out of the bucket as it breaks the water surface and is slewed over the attending barge, and intentional decanting of supernatant water through standpipes intended to increase the barge's effective load (USACE 2001). Bohlen et al. (1979) estimated that approximately 1.5 to 3.0% of the sediment is reintroduced to the water column by an operating bucket dredge, but they did not examine overflow practices. Tavolaro (1984) characterized scow overflow as a part of a more comprehensive sediment budget study for clamshell dredging and placement activities in which volume and solids concentration of the overflow was measured for scows of varying sizes. Tavolaro (1984) listed several factors influencing the character of the overflow to include: intensity of the dredging, degree of water entrainment during excavation, length of time of the overflow, and the care in which dredged sediments were placed into the barge. The study concluded that an average of approximately 2% of the dry mass of material placed in the barge will be lost to overflow. The authors drew no conclusions with regard to the load gain achieved in the barge as a result of decanting. However, the estimated loss of 2% of the dry mass of material placed into the barge has been described as untypically high by Dr. Paul Schroeder.[1] A distinction should be made between "overflow," as is commonly used to describe historical practices, such as hydraulic hopper dredge releases, and "decanting" used to describe the final loading phase of mechanically-filled barges. Although frequently used synonymously, decanting is the more accurate descriptor for the study reported herein.

[1] Schroeder, P. 2014. Personal communication with K. Reine. June 2014. Vicksburg, MS: U.S. Army Engineer Research and Development Center

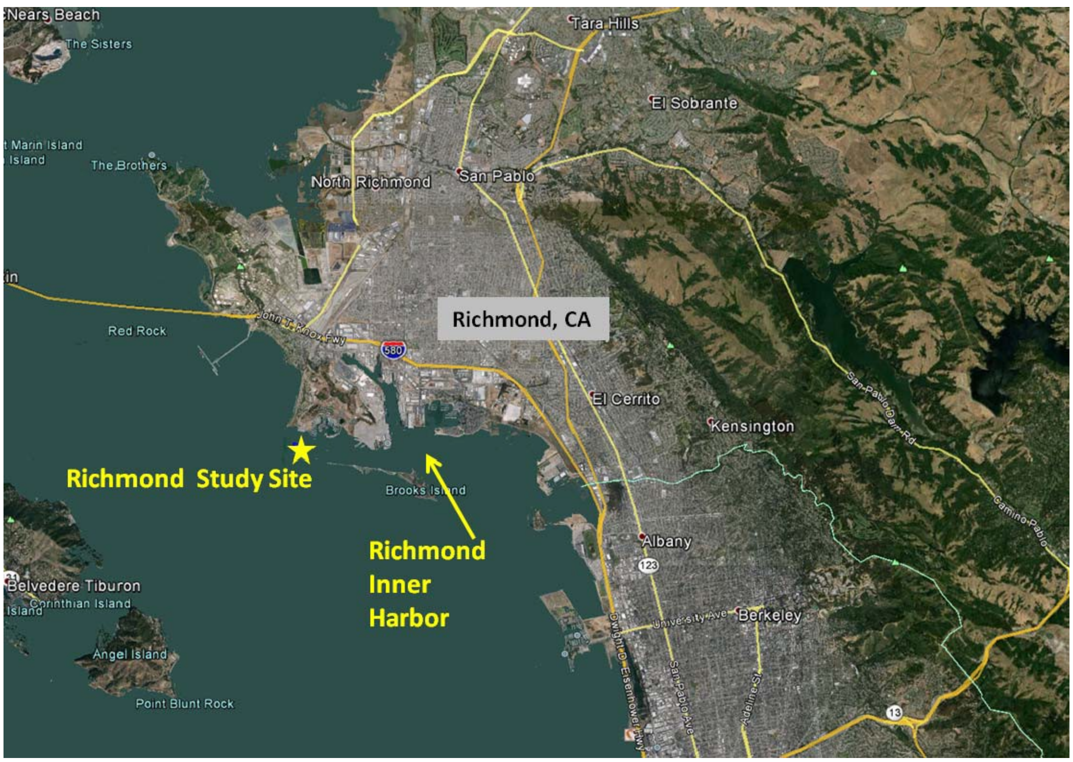
Since plumes, driven by tidal forces, change dynamically over large spatial scales and short-time scales, acoustic surveys offer advantages over traditional monitoring efforts in capturing data at appropriate spatial and temporal scales. An RD Instruments (RDI) acoustic Doppler current profiler (ADCP) was used to characterize the plumes created by both an operating bucket and the supernatant discharge resulting from decanting following a similar protocol used in Reine et al. (2002). In brief, the ADCP measures current velocities and direction by tracking acoustic energy returned from suspended particles being carried by water currents. This energy, or backscatter, can be used to derive estimates of suspended sediment concentrations. The major objectives of the study included: tracking and mapping plumes emanating from the dredging operation, to include the plume generated during decanting, and to quantify the additional loss of sediment during times of decanting. Decanting occurs in an attempt to optimize the sediment load and minimize water content transported to the placement site, thereby enhancing economic factors of the overall project. Economic load is the load in a dredge hopper or scow that corresponds to the minimum unit dredging cost. Economic load is dependent on the material dredged, equipment used, distance to the disposal site, and other site-specific factors. Economic load does not necessarily correspond to the maximum load or highest density load that can be obtained (Palermo and Randall 1989). Practices and problems associated with economic loading and overflow of dredge hoppers and scows can be found in Palermo and Randall (1989). As described below, a variety of logistical constraints prevented collection of comprehensive data as originally intended. However, the results successfully obtained by the team are provided.

3 Methods

Project Location

The City of Richmond, California is located in western Contra Costa County. The Port of Richmond is located southwest of the city of Richmond and to the east of the Southampton Shoal Channel and can be found on NOAA Chart 18653 at approximately 37^{o} 54’ N and 122^{o} 23’ W. The study site was located at the western terminus of the Point Potreno Reach, northeast of Brook’s Island, covering an area from 100 m east of Channel Marker “G-7” to approximately 200 m east of Channel Marker “R-6” (Figure 1).

Figure 1. Study Site.



Dredging Operation

Dredging was conducted by the *DB Palomor* using a 14-cubic yard closed environmental Cable Arm® bucket (Figure 2) operated by RES Engineering, Inc. The dredge has a 75-ton capacity crane with barge dimensions of 150’ x 54’ x 13’. For position maneuvering, it has the capability of using two 80’ spuds or four anchors and buoys. The latter anchoring technique was used during the present study.

Figure 2. Fourteen cyd closed environmental bucket used by the Dredge *DB Palomor* in the Port of Richmond.

Maintenance dredging at the Richmond Harbor site consisted of the removal of thin layers of material for a relatively low number of bucket cycles, given the small amount of material to be excavated at any given location. Dredging operations were therefore punctuated by frequent stoppages for repositioning of the dredge. Only 15 to 20 bucketloads were typically obtained at any given location before the dredge either advanced downstream or moved back upstream to start a “new cut” or “smooth” a previously dredged location. At this rate of material removal, nearly 24 hr were necessary to completely fill a single barge. Consequently, the barge decanting process, which occurs only after the barge is approaching full displacement, occurred on average only once per day. On several days the decanting process began and ended during nighttime hours; this prevented survey data collection due to safety concerns. Safety issues included, but were not limited to, the survey vessel operating near the active dredging operation during limited nighttime visibility and the usage of anchoring cables, which under some dredging operations may extend above the surface of the water near the dredge. Given the extremely limited spatial extent of the plume, the survey vessel had to operate in very close proximity to the dredge; this increased the risk of contact with the dredge’s mooring system.

Decanting Methodologies

Oakland Harbor

A description of the decanting methodology to be used at Oakland was described by the Manson Dredging Company. During the scow-loading process, the decant standpipe is closed, the scow is loaded until there is a standing head of water, and the material is just below the level of the top of the standpipe. At the conclusion of the loading process, the supernatant would be allowed to settle for one hour to allow for sediment to fall out of suspension. The scupper valve would then be opened and the water is then decanted all at once, which takes approximately 15-20 minutes. Once the headwater has drained, the scupper is closed and the scow is loaded to the remaining 80% capacity for offshore transport. This methodology was not monitored during the current study, given that the location of the study was changed on short notice from Oakland Harbor to Richmond Harbor due to leaking scows at the Oakland site. The Oakland Project would have used a larger dredge with multiple scows and may have produced a steady state plume instead of a "pulsed" plume of shorter duration.

Richmond Harbor

The decant operation used at Richmond Harbor differs significantly from that described above. Discussions with the Richmond dredging crew on site revealed that due to the water pressure, it is not practical to open the scupper valve if there is any significant head of water. This is understandable given that the scupper valve is simply a metal cap fitted to the top of the standpipe and, in some cases, the metal cap is manually opened and closed. In Richmond, the decant pipe remains open during the entire scow loading process, so there are only small periodic pulses of low-velocity, low-concentration decants with each bucket placement. Higher flow velocities during decanting should be expected if the above methodology is employed at the Oakland Harbor site. Given the "clean-up" nature of the dredging operation at Richmond, these small decants of water do not begin until approximately 18 hours into the barge-loading process. Once the level of the material reaches the bottom of the standpipe, which is placed at the 80% capacity level, the scupper valve is closed and the scow is ready for transport to the offshore placement area.

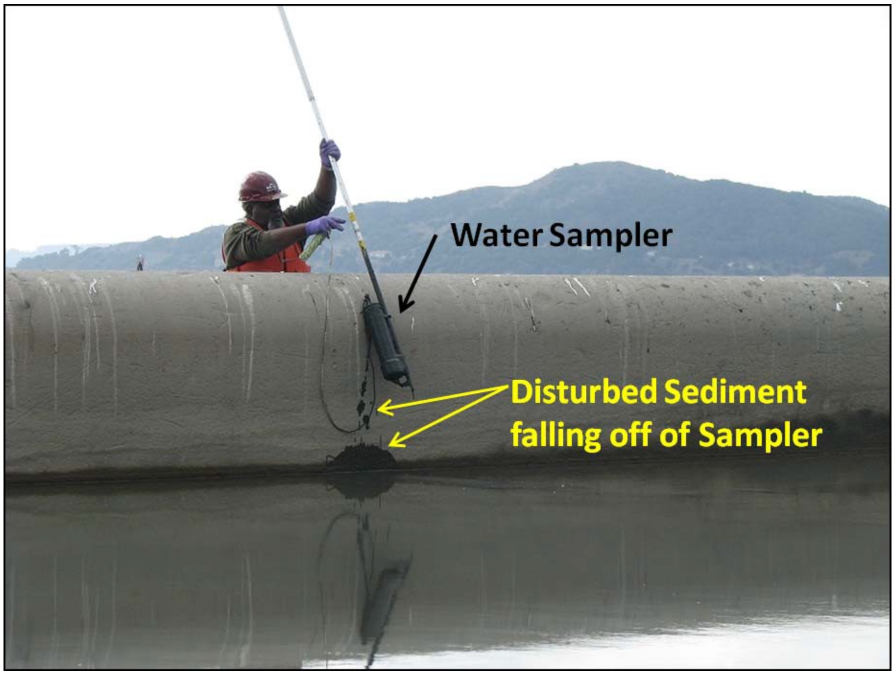
Collection of Supernatant and Calibration Water Samples

Supernatant water sample collection

Supernatant water samples of solids overflow from the barge were collected to determine the TSS concentration and discharge rate of solids into the water column. Mass flow results were applied over a pertinent mixing zone to determine a worst-case estimate TSS increase resulting from the decanting process. Typically, a second set of water samples are collected independently from the supernatant samples for calibration of the raw ADCP acoustic backscatter data conversion to TSS concentrations (discussed below). The collection of water samples is then analyzed for TSS and sediment grain size distribution (GSD). TSS concentrations are determined using standard laboratory procedures described in Plumb (1981). Grain-size data analysis was performed using Gradistat 8.0 (Blott and Pye 2001), which calculates a variety of grain-size parameters, as well as the percentages of sediments in individual grain-size categories. Grain-size parameters and descriptions will be based on the methods described by Folk and Ward (1957), and Folk (1968).

The sampling frequency for typical decanting operations during tracking TSS plumes is 30 standpipe samples per scow, collected during active discharge of the supernatant water. A minimum volume of 100 ml should be captured for determination of TSS. Every sixth sample will be analyzed for GSD and should have a minimum volume of 250 ml. In addition, a minimum of five surface water samples will be collected, along with a corresponding sediment sample of the dredged material deposited into the scow. Samples should be taken periodically from the ponded water during the free-water buildup. Samples should be taken continuously, as frequently as is practicable, throughout the drawdown (decanting) process. Samples will be obtained using a bottle holder attached to either a rigid pole or other sampling apparatus as dictated by safety and scow logistics. Figure 3 depicts the sampling apparatus during supernatant water collection.

Figure 3. Sampling of decant water for TSS concentrations. Supernatant water depths in the scow rarely exceeded a few in., making it impossible to collect water samples without disturbing the sediment below and corrupting the results. Note sediment falling off the sampler as it is raised out of the barge.



Calibration water sample collection

In order to convert backscatter data (decibel units) to suspended sediment concentrations (mg/L), the ADCP data must first be calibrated against known concentrations. To accomplish this step, water samples must be collected at specific locations within the ADCP beam and at multiple locations in the plume, exhibiting both a range of concentrations and distance from the source. Water samples are then analyzed gravimetrically using standard methods. Water sample TSS concentrations are then matched to an exact acoustic ping number in the corresponding ADCP data file as described in Land and Bray (2000). In this manner, for each ADCP calibration file, there is a corresponding water sample of a known TSS concentration. Differences between known and estimated sediment concentrations are then examined and corrected in the Sediview® data analysis program. The calibration results, from which Sediview® derives estimates of TSS concentration, are compared to the observed values based on TSS gravimetric analyses.

Current Structure

ADCP data provided characterization of prevailing water circulation in the Point Potrero Reach of Richmond Harbor. Raw data for all ambient and plume transects were processed and examined for evidence of stratified flows, tidal eddies, and other patterns that could influence plume dispersion.

Data Collection and Processing

An RD Instruments 600-kHz Mariner Workhorse® Series ADCP was used to collect current velocity, direction, and backscatter data. RD instruments WinRiver® software running on a laptop computer was used for both data collection and display. WinRiver® software determines and records velocity and direction in predetermined vertical bins along each transect surveyed. Vessel direction and speed and current velocity in three directional axes (manufacturer's stated accuracy of $\pm$ 0.2 cm/sec) were recorded at selected collection data ranges. An internal fluxgate compass allowed the instrument to correct ADCP current velocity and direction regardless of vessel speed or orientation. Monitoring of the dredge plume was conducted from a "Safe Boat" operated by the U.S. Army Corps of Engineers San Francisco District (SPN). The vessel was equipped with a side-mounted aluminum frame for deployment of the ADCP transducer. A specific serial file name was created by the acquisition software for each transect. Data collection parameters were entered and stored in a configuration file. A third file, consisting of navigation data received from an external differential global positioning system (DGPS) with an accuracy of $\pm$3 meters was also collected and used in data post-processing. ADCP raw backscatter data were analyzed using Sediview Software provided by Dredging Research LTD. The Sediview Method (Land and Bray 2000) derives estimates of suspended solids concentration throughout the water column based on acoustic backscatter data collected by the ADCP.

Survey Design

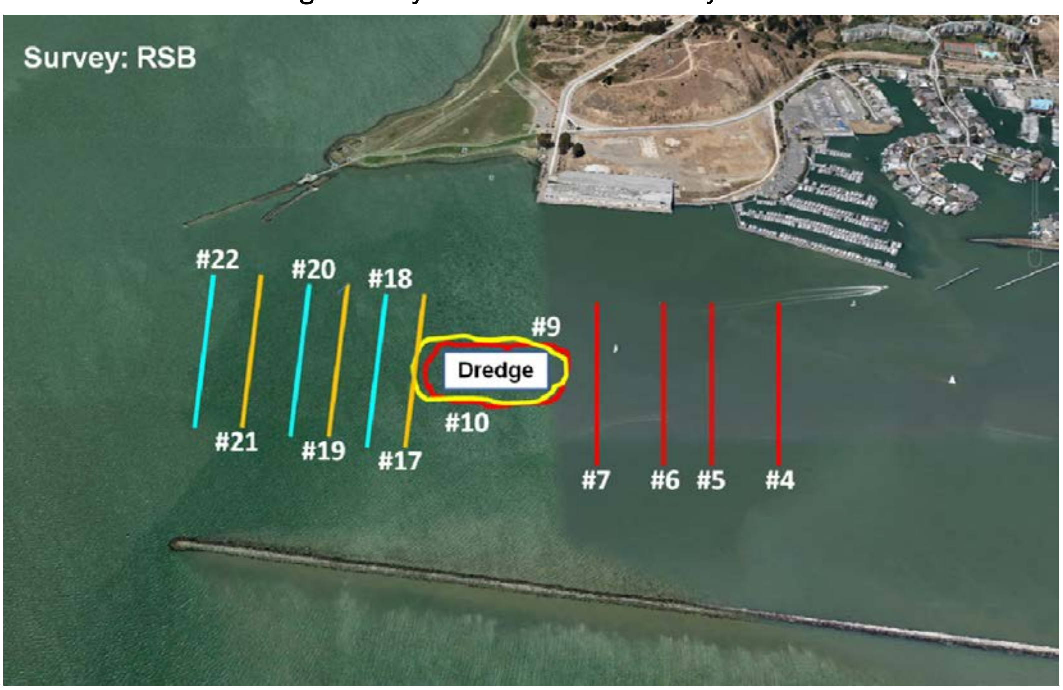
Ambient Survey

Since the dredge was fully operational prior to the arrival of the survey crew, ambient data collection was limited to the upstream side (opposite to net current flow) of the dredge and/or to times when the dredge had completely shutdown for maintenance, crew changes, or other reasons. Transects RSA-1 through RSA-3 (Figure 4) and Transects RSB-4 through

RSB-7 (Figure 5) are representative files depicting ambient conditions. Transects extended laterally across the navigation channel in a north-south direction. Transect length ranged from 49 to 70 m (mean = 58 m).

Figure 4. Layout of transects for Survey RSA.

Figure 5. Layout of transects for Survey RSB.



Ebb Tide Survey

Data collection during an ebbing tide occurred on 8 November 2012. Two surveys were completed. Survey RSA consisted of 10 transects. Transect RSA-8 encircled the dredging operation. Six transects covered a downstream portion of the study site progressing westward from the dredge towards Channel Marker R-6. Downstream extent of the survey was based on the observed decay of the plume in comparison with ambient conditions (Figure 4, RSA-11 through RSA-16). The first of these downstream transects (RSA-11) passed within 30 m of the point of bucket entry and exit from the water. The final transect in the series was occupied 298 m down-current of the dredging operation. Note that transects RSA-1 through RSA-3 were discussed in the above paragraph under the heading "Ambient Survey." A plan-view layout of transects is depicted in Figure 4. Transect length ranged from 51 to 119 m (mean = 70 m).

A second attempt was made to map the plume resulting from decanted water once dredging operations had resumed. Twelve parallel transects were occupied both up- and downstream from the dredge. Transects RSB-4 through RSB-7 were occupied on the upstream, east side, of the dredge to determine ambient concentrations because plume movement was in a southwesterly direction. Transects RSB-9 and RSB-10 encircled the dredging operation at a distance of 40 m and 45 m, respectively. This distance was to the bucket as the transect passed in front of the dredging operation and not the distance in which the transect passed alongside (port and starboard) of the scow to map the decanted plume. Distance to the scow was typically on the order of 1 m. Transects RSB-17 through RSB-22 were occupied downstream in the direction of plume movement at increasing distances ranging from 50 m to 296 m. A plan-view layout of transects for Survey RSB is depicted in Figure 5. Transect length ranged from 49 m to 117 m (mean = 68 m).

Flood Tide Survey

Given the small number of opportunities to map the plume, no surveys were completed during flood tide.

4 Results

Calibration Issues

Several factors prevented collection of sufficient water samples during either discharge of the supernatant or plumes generated by sediment excavation, including (1) the very short duration of the discharge; (2) that no plume was detected by the ADCP that was associated with decanting of the supernatant discharge; (3) the rapid settling and decay of the plume; and (4) the limited downstream movement of the detectable plume generated by the bucket where sediment concentrations were highest did not extend beyond 125 m. At this distance, the majority of the plume signature with highest TSS concentrations is located in the near-field zone and was greatly influenced by entrained air. Air injected into the water column by the insertion and removal of the bucket or through the discharge standpipe greatly exaggerates TSS estimates, rendering the calibration useless. Air bubbles in currents as slow as those at the present study site were still present at distances of up to 125 to 150 m. At no time was a definitive, distinct, identifiable plume signature detected by the ADCP that was a result of the decanting discharge. Consequently, no water samples for gravimetric analysis could be obtained from the discharge plume to determine the range of concentrations associated with the decanting process. The majority of the plume volume resulting from the decant discharge obviously remained beneath the dredge scow. Observations and photographic records indicated that a significant amount of air was released through the standpipe.

Caveat: To convert the ADCP backscatter to TSS concentration in the present study, a calibration file obtained from a previous plume characterization conducted in Richmond Inner Harbor was used. TSS estimates in all vertical profiles should therefore be reasonably accurate, given consistent sediment type and current velocities. Based on the comparable size and type of bucket used as well as many years of experience conducting plume characterizations, an error rate of plus or minus 10% of the stated concentration estimate would be reasonably conservative. Note that at distances of less than 150 m, estimated “actual” TSS estimates are approximately 50% of that measured by the ADCP due to entrained air.

Collection of Supernatant and Calibration Water Samples

Because the standpipe was allowed to remain open at all times (Richmond methodology), the layer of water above the dredged sediment was very shallow. This issue would not have been a problem at the Oakland dredging site. The closed standpipe using the proposed Oakland methodology would have provided for sufficient water depth within the barge to collect undisturbed water samples. Multiple attempts were made to collect water samples without disturbing the sediment placed in the scow, which corrupted the results. These attempts were almost entirely unsuccessful. For example, Figure 3 shows dredged sediment dropping off the sampler upon retrieval.

Ebb Tide Current Structure

Water velocities were weak, averaging less than 0.2 m/sec. Flows diminished to approximately 0.1 m/sec for transects located furthest east of the dredging operation. Movement of water was generally in a west-southwesterly direction (240 to 269^0). No indication of increasing or decreasing flow velocities was seen as the survey progressed. The lack of strong flows contributed to the apparent randomness of the directional vectors (Figure 6), as the ADCP had difficulty resolving direction at such slow velocities (RDI 2003).

Ambient TSS Concentrations

No opportunity was available to conduct an ADCP survey in the absence of the dredge. However, the general range of ambient TSS concentrations was estimated on the basis of data collected outside of the area of plume influence, typically in an area located upstream (east) of the dredge, as net movement of water was generally in a westerly direction. The first full survey (RSA) was completed during a period of little dredging activity (i.e., active dredging for 22 min, before repositioning to a new location), and can be examined for an approximation of ambient conditions. Figures 7 through 9 (Transects RSA 1 through RSA 3) depict ambient TSS concentrations of less than 20 mg/L throughout the majority of the water column. A small area of disturbed sediment at the intersection of the channel basin and side slope can be seen on the left side of Figure 7 (RSA 1). It is uncertain if this represents a residual plume or resuspension due to currents along the side slope of the channel. TSS concentrations were consistently less than 40 mg/L at the channel side slope interface.

Figure 6. Vector profile showing somewhat random directional vectors due to lack of strong current flows at the study site. Net movement of water was in a west-southwesterly direction during ebb tide.

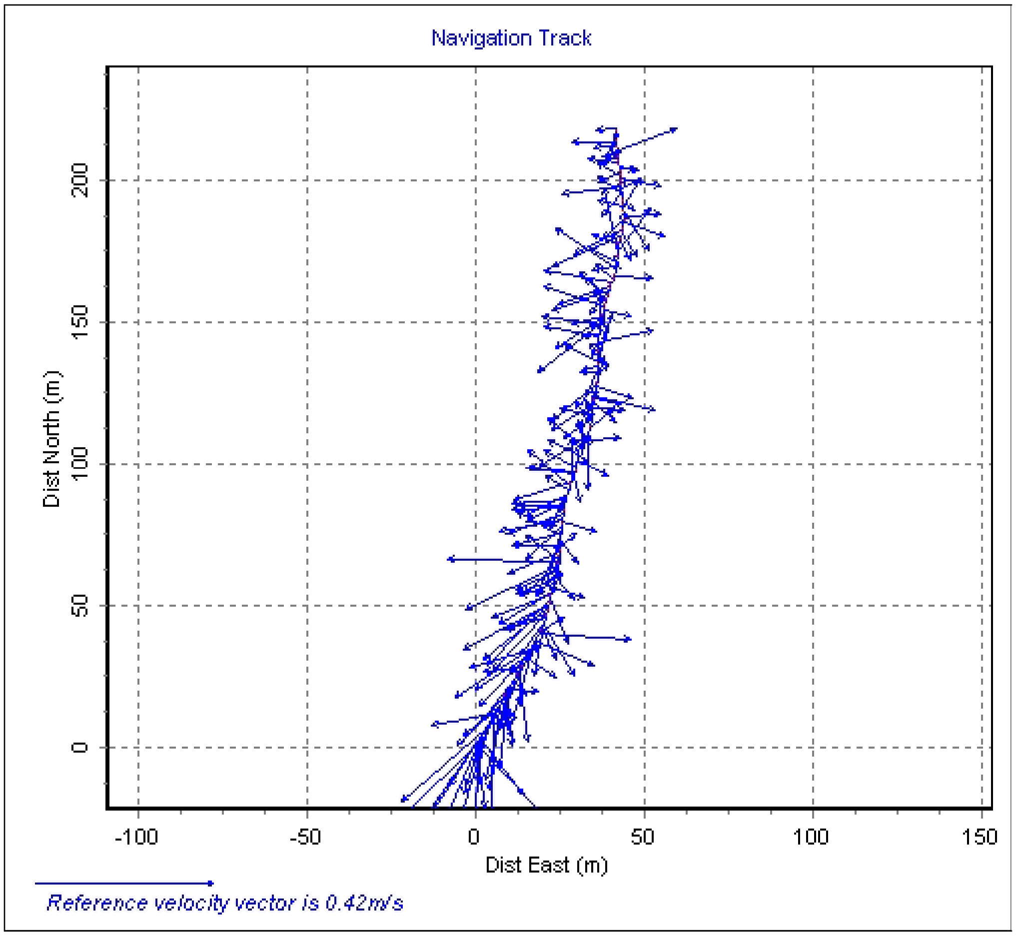


Figure 7 (RSA-1). Transect occupied 93 m up-current from the dredge in the opposite direction of plume movement. Small amount of plume located along the channel bottom, near the tow of the channel side slope. A small amount of entrained air, associated with the passing of a small motor boat, is visible on the upper left side of the vertical profile at water depths less than 3 m.

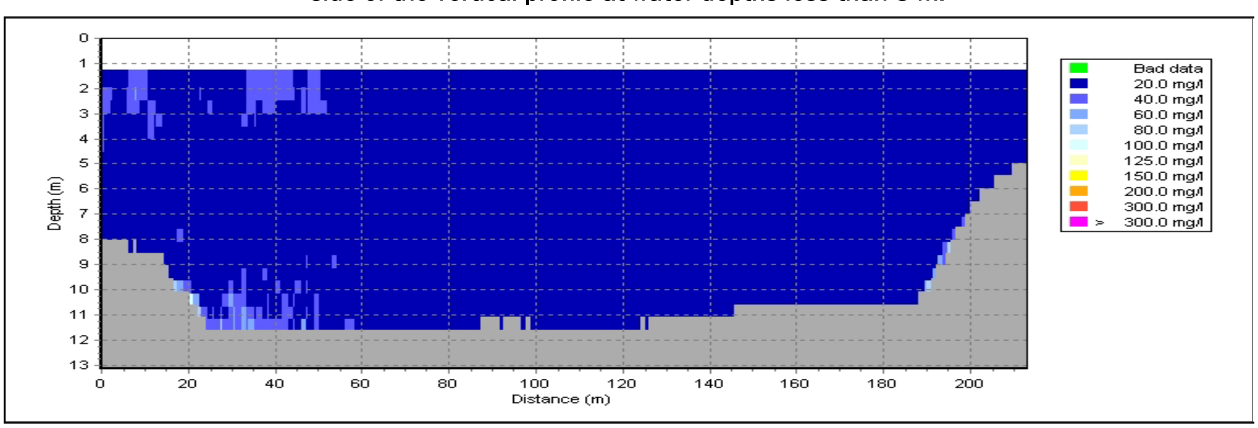


Figure 8 (RSA-2). Transect 149 m from the dredge. Dredge has resumed full production. No plume detected by the ADCP or visible upon the water surface. All TSS concentrations were at or below ambient condition. Transect heading is 340°.

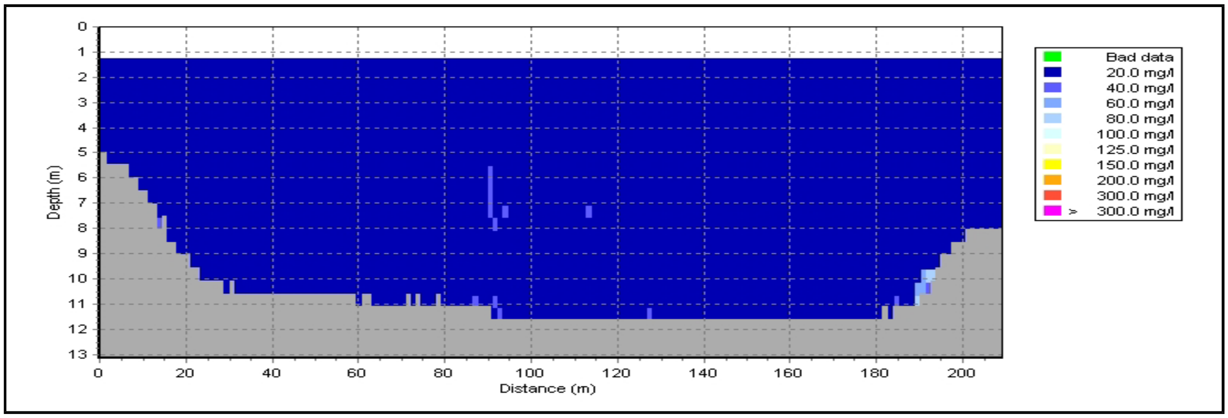
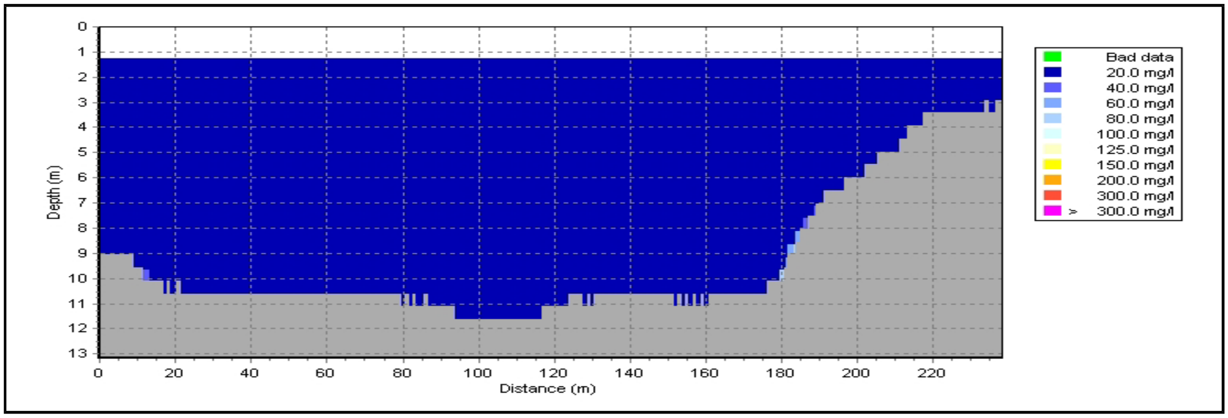


Figure 9 (RSA-3). Transect 217 m from the dredge. Dredge has resumed production. No visible plume detected by the ADCP or upon the water surface. TSS concentrations were at or below background. Transect heading is 160°.



Four additional ambient transects were occupied as part of a second survey. Figures 10 through 13 (Transects RSB-4 through RSB-7) consisted of a series of four parallel transects occupied east of the dredge's location, opposite to the direction of net current flow. Again, TSS concentrations remained less than 20 mg/L along all four upstream transects. As seen in the previous ambient transects, TSS concentrations along the immediate channel bottom were as high as 40 mg/L. This area of higher TSS concentrations typically occurred in the lower 1 m of the water column. Based on these two surveys, TSS concentrations equal to or below 20 mg/L will be assumed to represent ambient conditions for comparison to plumes generated by the dredging process. However, ambient TSS concentrations in the lower 1 m of the water column may be as high as 40 mg/L. A conservative value of 20 mg/L will be used for the entire water column to compare to TSS values obtained from suspended sediment plumes.

Figure 10 (RSB-4). Ambient transect occupied 233 m upstream, astern of dredge (east of dredge position). Transect heading is 165°. Some residual plume with TSS concentrations less than 40 mg/L, exceeding ambient by less than 20 mg/L occur in the lower 1 m of the water column.

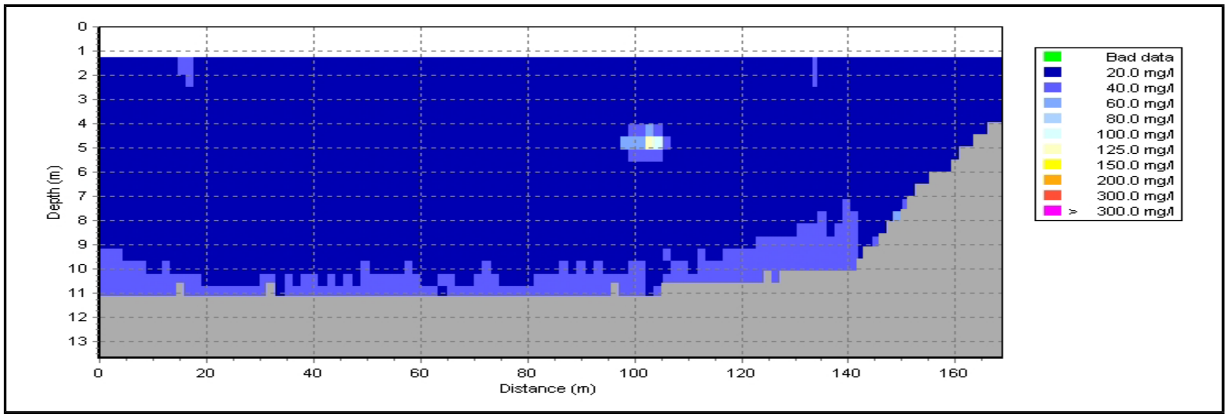


Figure 11 (RSB-5). Ambient transect occupied 150 m upstream and astern of dredge (east of dredge position). Transect heading is 356°. Some residual plume with TSS concentrations of less than 40 mg/L, exceeding ambient by less than 20 mg/L, occur in the lower 1 m of the water column.

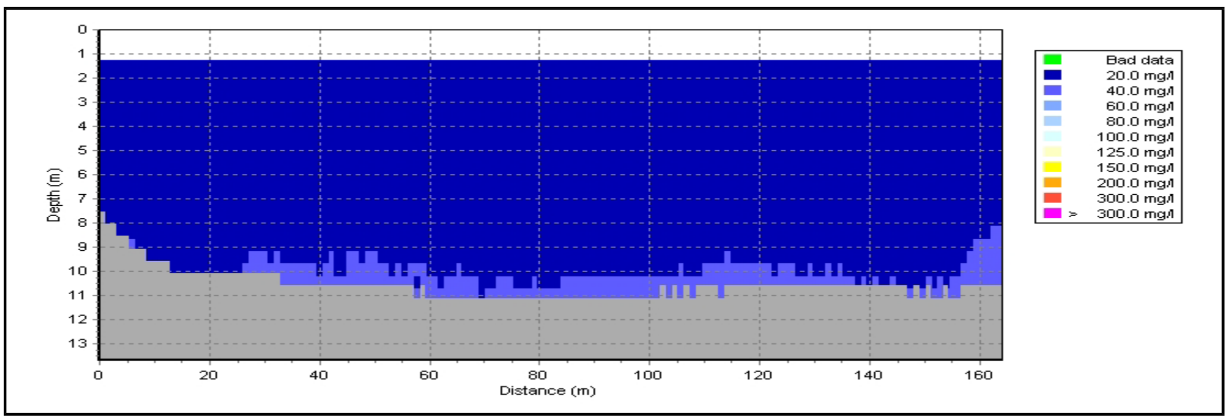


Figure 12 (RSB-6). Ambient transect occupied 127 m upstream and astern of dredge (east of dredge position). Transect heading is 162°. Some residual plume with TSS < than 40 mg/L, exceeding ambient by less than 20 mg/L, occur in the lower 1 m of the water column.

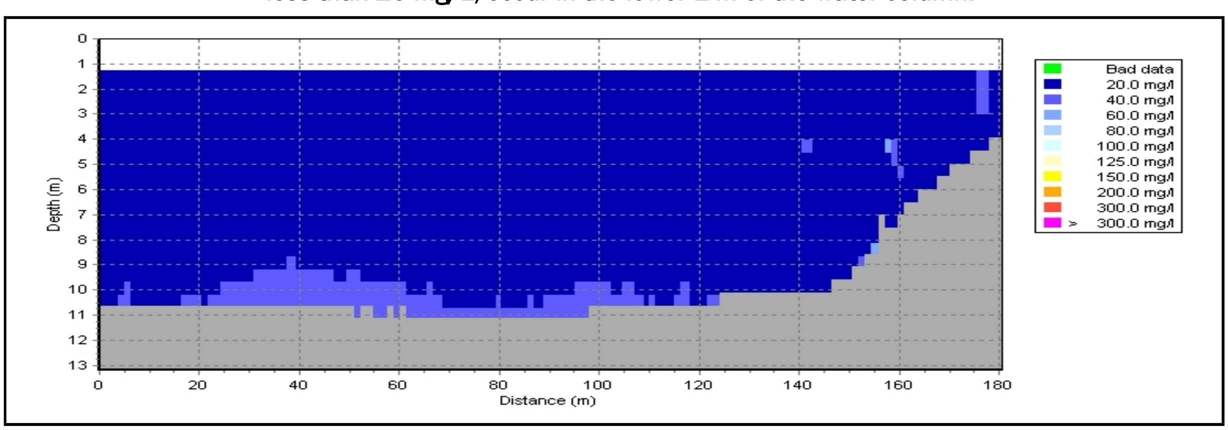
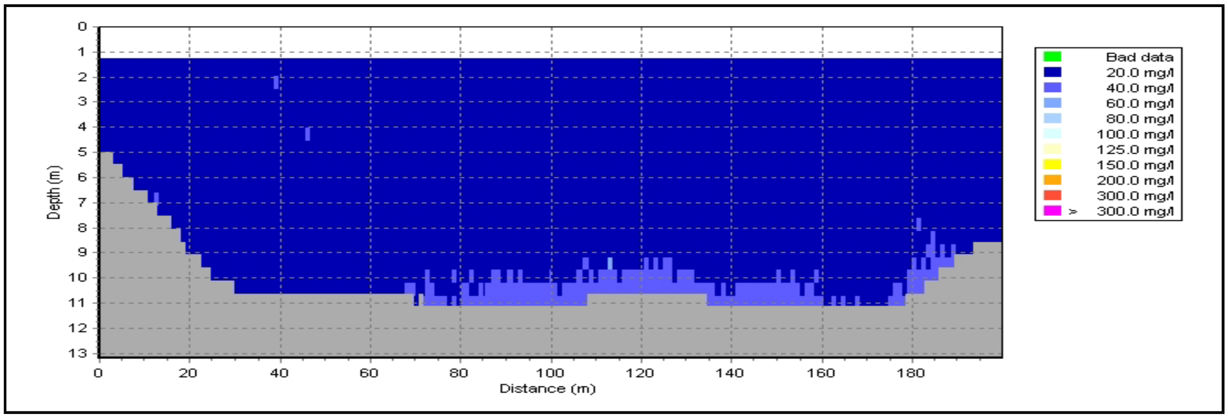


Figure 13 (RSB-7). Ambient transect occupied 76 m upstream and astern of dredge (east of the dredge position). Transect heading is 355°. Some residual plume with TSS concentrations of less than 40 mg/L, exceeding ambient by less than 20 mg/L, occur in the lower 1 m of the water column.



Decanted Plume TSS Concentrations

Examples of TSS vertical profiles taken in close proximity to the dredge scow are given in Figures 14 through 16 (RSA-8, RSB-9 and RSB-10, See Figures 4 and 5 for transect layout). These three transects encircled the dredging operation passing to within 1 m or less of the barge scow. Figure 14 (RSA-8) shows a very distinct plume generated by the bucket during sediment removal. The three yellow arrows represent directions starboard, port, and astern of the dredge scow in the areas where the decant plume would be expected. No evidence of the decant plume was observed on the ADCP vertical profile or visually on the water surface by the field crew. Figure 15 (RSB-9) depicts a small plume of very low TSS concentrations (< 40 mg/L) confined to the lower 2 m of the water column. It is uncertain whether this small area of higher TSS concentrations is associated with the decanting process or residual plume. When factoring in ambient TSS levels, this small plume would exceed background levels by no more than 20 mg/L. Figure 16 (RSB-10), repeated Transect RSB-9 approximately 1 hr later. The ADCP did not detect any evidence of increased TSS due to decanting.

Ebb Tide Plume Characterization

Plume structure can be examined in enhanced detail in vertical cross-sectional profiles representing the series of individual transects comprising the survey (See Figure 4 for survey RSA). Figure 14 (RSA-8) encircled the dredging operation and depicts a well-defined plume approximately 30-m from the point of excavation. Note that this plume is not associated with decanting discharge, but the result of the sediment excavation process. Decanting occurred at the rear of the scow, so any decanting discharge plume detected by the ADCP would be present along the extreme left and

Figure 14 (RSA-8). Circle around the dredge (See Figure 4 yellow circle). Plume generated by sediment excavation, 30 m from the source. Plume movement is in a westerly direction. No evidence of decanting discharge signature in ADCP concentration profile. Yellow arrows indicate port, starboard, and astern positions relative to the dredge scow in the areas of expected decant plume location.

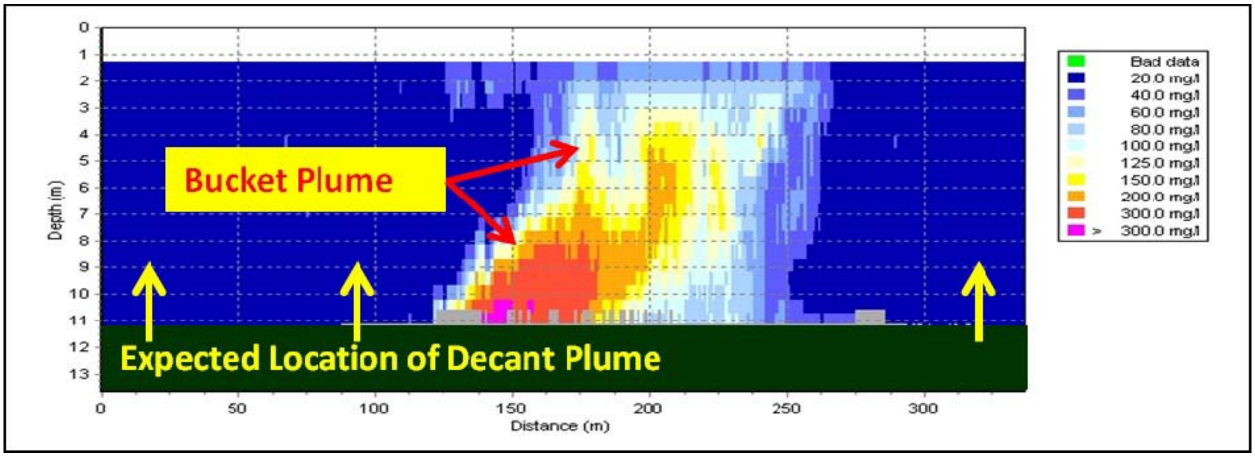


Figure 15 (RSB-9). Transect encircled the dredging operation. (Figure 5, red circle). Main body of plume with highest TSS concentration was measured at 40 m down-current from the dredging operation and is associated with the sediment excavation process. Prop wash from a tug depicted on far right side of the vertical profile extending from surface to 6 m water depth. The plume signature on the left side of the vertical profile, port side of the scow, may be associated with the decanting process.

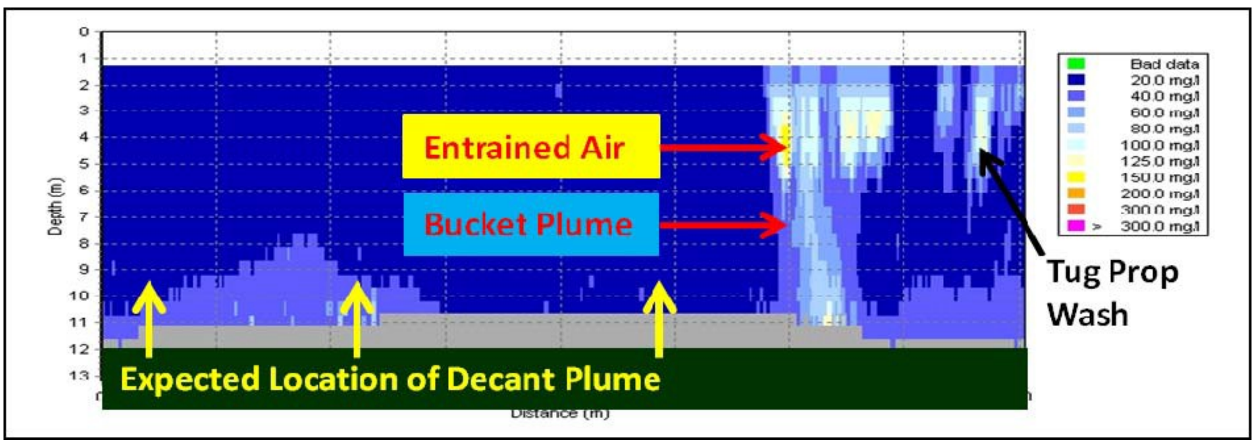
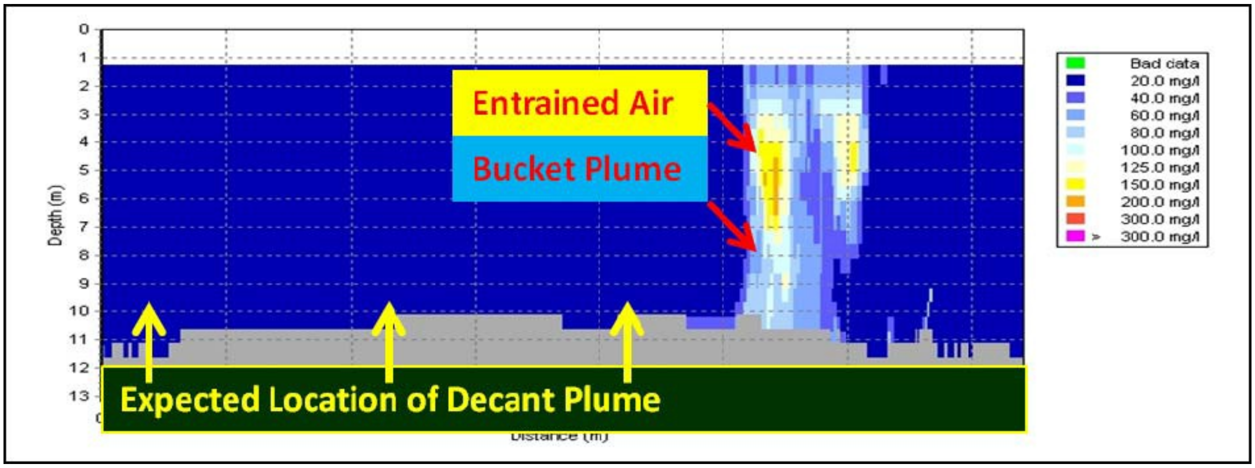


Figure 16 (RSB-10). Transect encircled the dredging operation (Figure 5, yellow circle). The plume is associated with the sediment excavation process and not decanting. Transect occupied 40 m from the bucket. Note: entrained air is suspected in the plume signature at this distance. This transect repeats the above transect (Figure RSB-15) 1 hour later.



right sides of the ADCP vertical profiles. TSS concentrations outside of the plume generated by the sediment excavation process are well within background levels. The plume generated by the dredge bucket was slightly more than 200 m wide and extended vertically throughout the entire water column. TSS concentrations were less than 300 mg/L in the lower 2 m of the water column. TSS estimates at this distance down-current from the dredge were highly influenced by air entrainment and are therefore exaggerated. TSS concentrations exceeded 150 mg/L at all water depths, with the exception of the upper 3 m. Surface concentrations were generally less than 60 mg/L, exceeding ambient by 40 mg/L. Due to the amount of entrained air, actual TSS estimates in the near-field zone would be approximately 50% of that estimated by the ADCP. For all transects, a conservative ambient value of 20 mg/L will be applied to the entire water column. Adjusting for air entrainment, maximum TSS concentration would be closer to 150 mg/L in the lower 2 m of the water column, exceeding ambient by 130 mg/L.

Figure 17 (RSA-11) depicts the plume at a distance of 60 m down-current from the dredging operation. Highest TSS concentrations (125-150 mg/L) fell by as much as 50% from the previous transect occupied 30 m closer to the dredge, a clear indication that the previous transect had a significant amount of entrained air. TSS concentrations at this distance were still greatly influenced by the presence of entrained air. With that caveat, highest TSS concentrations would range from 105 to 130 mg/L above ambient (minus entrained air would decrease this to 50 to 65 mg/L). Much of the area shaded in yellow is obviously corrupted by air bubbles. In the lower 1 m of the water column, where air bubbles had risen to shallower water depths, TSS concentrations were less than 100 mg/L, exceeding ambient as much as by 80 mg/L. The central portion of the plume containing the highest concentrations decreased in size to a swath less than 40 m wide.

Figure 17 (RSA-11). Transect occupied 60 m from dredge. Dredge removing sediment with decanting from the scow. Plume depicted generated by the bucket. Plume movement is in a westerly direction.

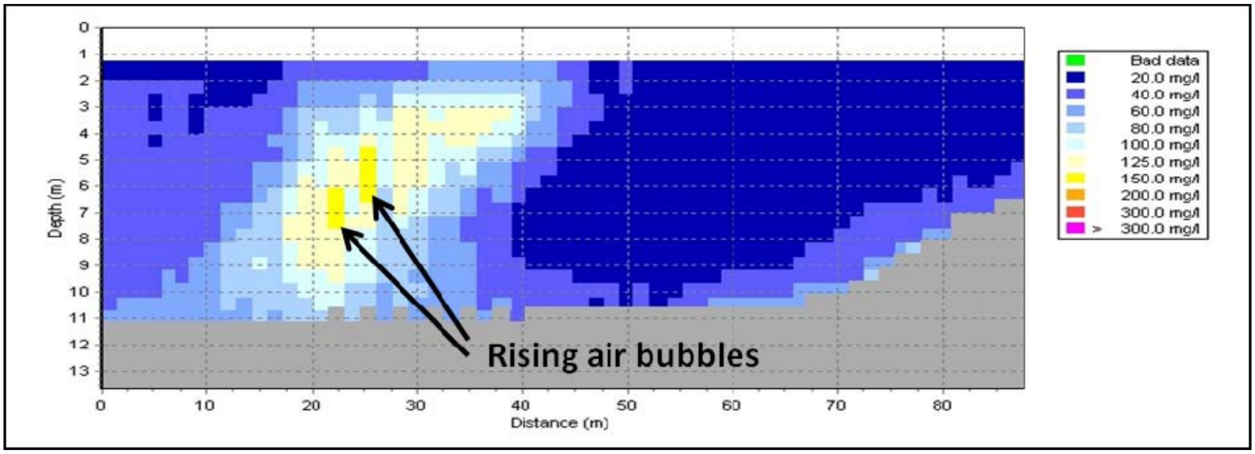


Figure 18 (RSA-12) shows a rapidly decaying plume located only 110 m from the source. Entrained air is still present in the upper 2 to 5 m of the water column. The majority of the plume's volume has TSS concentrations of less than 40 mg/L, exceeding ambient by 20 mg/L. An area along the channel side slope has slightly elevated TSS concentrations, consistent with ambient conditions observed earlier.

Figure 18 (RSA-12). Transect occupied 110 m from the dredge. Dredge removing sediment with overflow. Plume depicted is from sediment excavation. Decanting plume not detected. Plume movement is in a westerly direction.

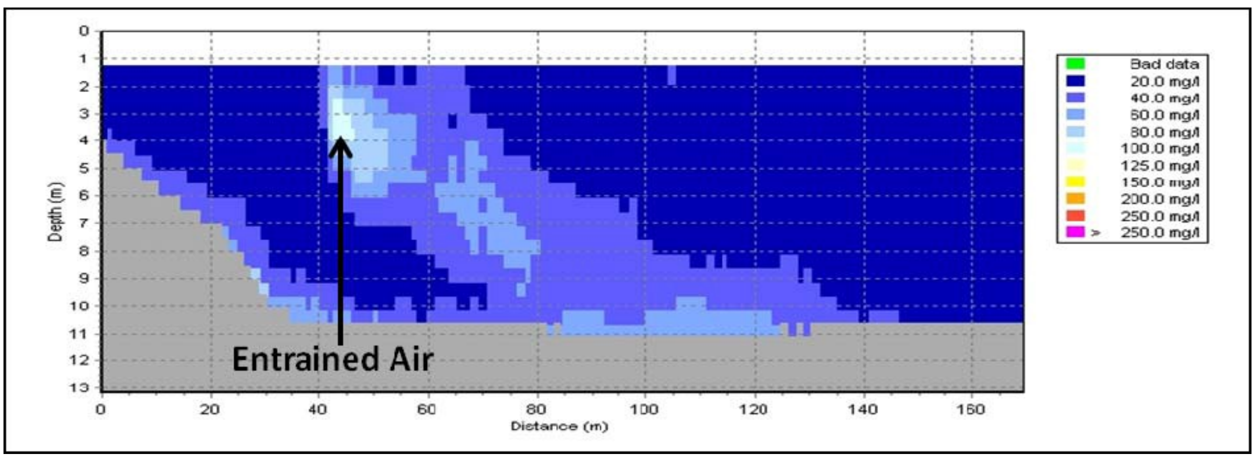


Figure 19 (RSA-13) is the final transect in which the plume signature extended from surface to bottom. This transect was occupied only 132 m from the dredging operation. A small area of entrained air is visible on the far right side of the ADCP vertical profile between depths 2 and 5 meters. TSS concentrations exceeded ambient by less than 20 mg/L throughout the water column. The dredge stopped removing sediment at the completion of this transect, although the supernatant was still discharging from the scow. The total elapsed time the dredge was removing sediment was 22 min.

Figure 19 (RSA-13). Transect occupied 132 m from dredge. Dredge is shutdown but still overflowing. Plume depicted is from sediment excavation. No evidence of decanting plume. Dredge stopped digging after the completion of this transect. Total time removing sediment was 22 min.

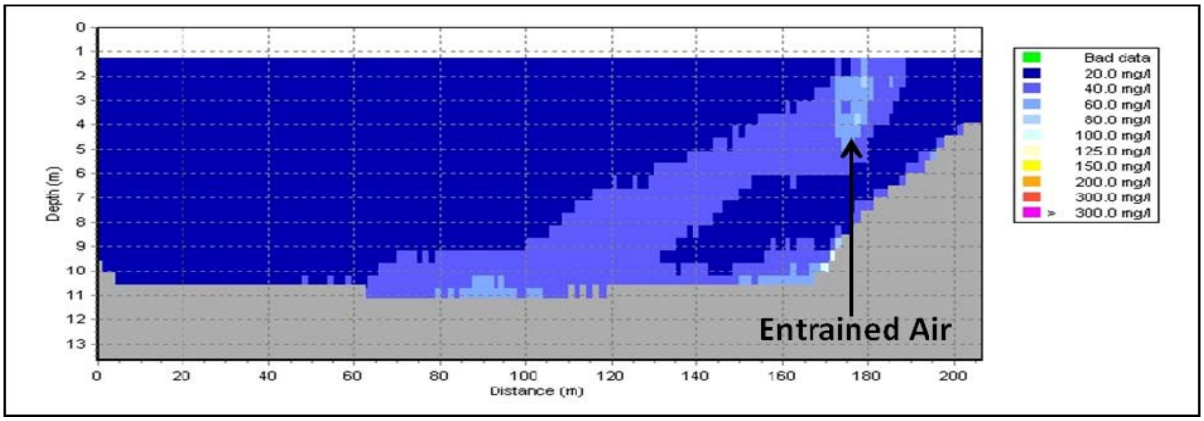


Figure 20 (RSA-14) shows only a faint plume located 160 m from the dredge in the lower 2 m of the water column, 7 min after the dredge stopped removing sediment. Figure 21 (RSA-15) occupied 258 m down-current of the dredge shows the remnants of the decayed plume, located along the channel bottom, 9 min after cessation of dredging. Figure 22 (RSA-16) shows a return to ambient conditions throughout the entire water column, 13 min after the cessation of dredging activities. A small area of entrained air associated with the prop wash of a passing motor vessel is located on the left side of the vertical profile.

Second Ebb Tide Plume Characterization Survey

A second during-dredging ebb tide survey (RSB) produced similar results. A plan-view layout of the survey transects is presented in Figure 5. Figures 10 through 13 (RSB 4 through RSB-7) consisted of a series of four parallel transects (Figure 5, red transect lines) occupied east of the dredge's location, opposite to the direction of current flow, to map ambient TSS concentrations (discussed in a previous section). Background TSS concentrations averaged less than 20 mg/L.

Figure 20 (RSA-14). Transect occupied 160 m from the dredge. Dredge is not digging, but in the process of moving to next "cut." Transect heading is 160°. Vertical profile shows rapid decay of plume within 8 min after the dredge stopped excavating sediment.

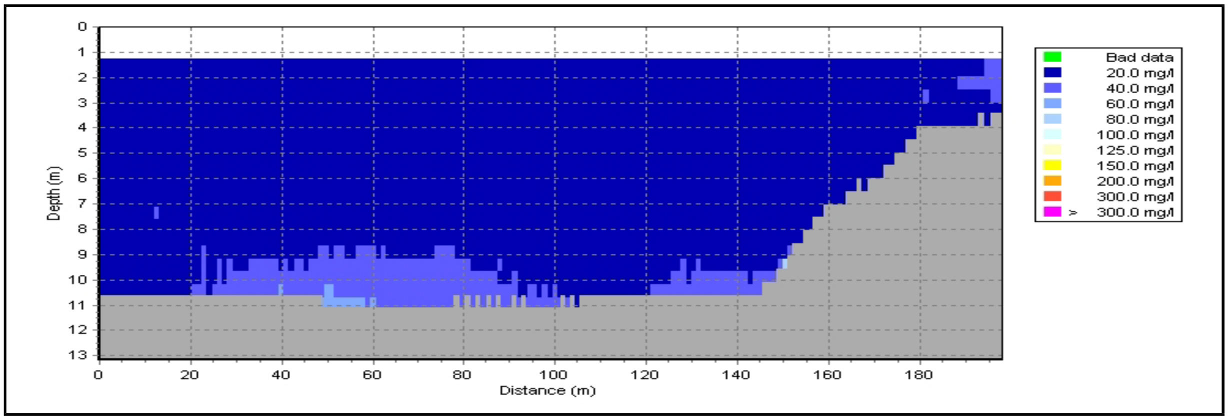


Figure 21 (RSA-15). Transect occupied 258 m from the dredge. Dredge is not digging. Transect heading is 160°. TSS concentrations at or near ambient at all depths with the exception of a small faint plume signature in the lower ½ m of the water column.

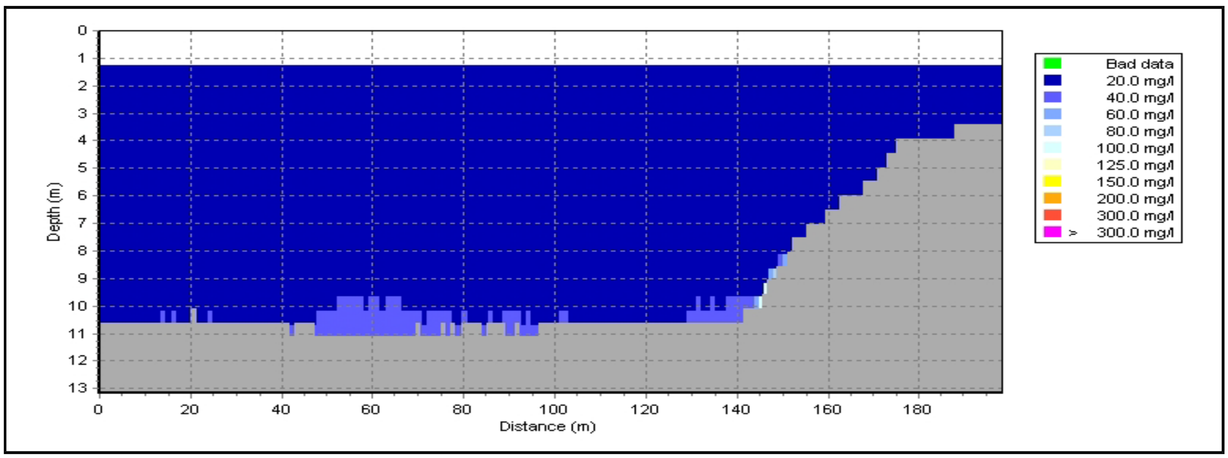
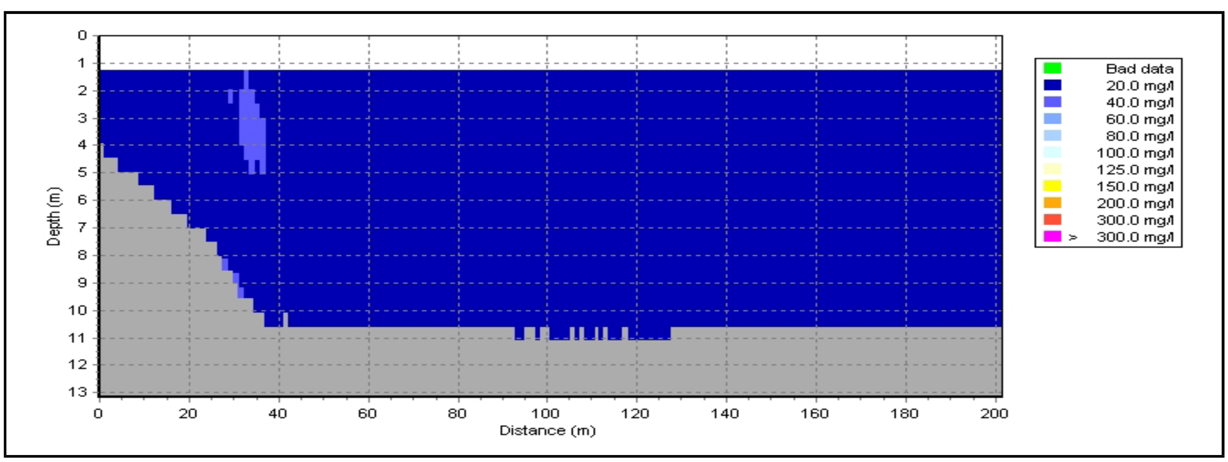


Figure 22 (RSA-16). Dredge and survey moved east to a new location. Transect occupied 296 m from the dredge (Transect heading was 340°). Dredge not digging. TSS concentrations were below ambient conditions. Entrained air (left side of profile) associated with the passing motor vessel.



Examination of TSS concentration gradient structure on the vertical cross-sectional profiles comprising the survey again indicated that the plume was a relatively narrow band (< 75 m) of increased TSS concentrations initially occupying the entire water column. Transect RSB-9 (Figure 15) encircled the dredging operation (Figure 5, red circle) passing within 45 m from the point of sediment excavation (not the distance to the location of the expected decant plume, distance to barge was typically 1 m). Maximum TSS concentrations were less than 150 mg/L. (~75 mg/L in the absence of entrained air). Both the vertical profile, as well as visual observations during data collection, indicated the presence of significant air bubbles contributing to an inflated TSS concentration estimate. On the far right side of the vertical profile is a signature from propwash generated by a tugboat. This signature serves as an example of how entrained air can dramatically inflate the TSS estimate. The propwash acoustic signal has no suspended sediment (only air bubbles); although the estimates generated by the ADCP are upwards of 125 mg/L. Located on the left side of this vertical profile is a small plume signature occupying the lower portion (8-12 m) of the water column. TSS concentrations were less than 40 mg/L, exceeding background by 20 mg/l. Two possible explanations of the presence of this small plume are (1) movement of sediment from the point of excavation along the channel bottom and/or the presence of a residual plume; (2) sediment resuspension due to the interaction of currents and the channel side slope; and (3) detection of a plume associated with the decanting process. If the latter, this would be the only transect occupied during the study in which the decanting discharge plume was definitely detected as a feature distinct from the plume generated by the sediment excavation process. However, given the short distance to the dredge scow at which the survey vessel passed (~ 1 m) and the low overall concentrations levels, the decanting discharge plume would not represent a significant feature even when compared to the small plume generated by the excavation process.

Figure 16 (RSB-10) also encircled the dredging operation (Figure 5, yellow transect line), passing within 40 m of the insertion point of the dredge bucket (again, not the distance to the area of the expected decant plume). Again a well-defined plume signature is evident against ambient conditions located both to the north and south of the plume signature. Unlike the previous transect (RSB-9, Figure 15), which encircled the dredge where a small plume, possibly generated by decanting, was detected in the lower portion of the water column; no plume was detected outside of that generated by the bucket during sediment excavation. This transect casts doubt that the low concentration plume on the left side of RSB-9 (Figure 15) was associated with the decanting process. As seen previously, transects occupied this close to the dredging operation had significant air entrainment. Maximum TSS concentrations estimated by the ADCP were slightly less than 200 mg/L. Actual estimates are more realistically closer to 100 mg/l, exceeding ambient by 80 mg/L. The plume signature was confined in a narrow band less than 50 m wide. The plume did not show any signs of lateral movement (north-south) out of the navigation channel at this distance. There was little change in the plume structure on Transect RSB-17 (Figure 23), occupied only 10 m down-current from the previous transect.

Figure 23 (RSB-17). Transect occupied 50 m downstream from the dredge. Plume signature is from the sediment excavation process. A separate decanting discharge plume was not detected. Note: entrained air is suspected in the plume signature at this distance.

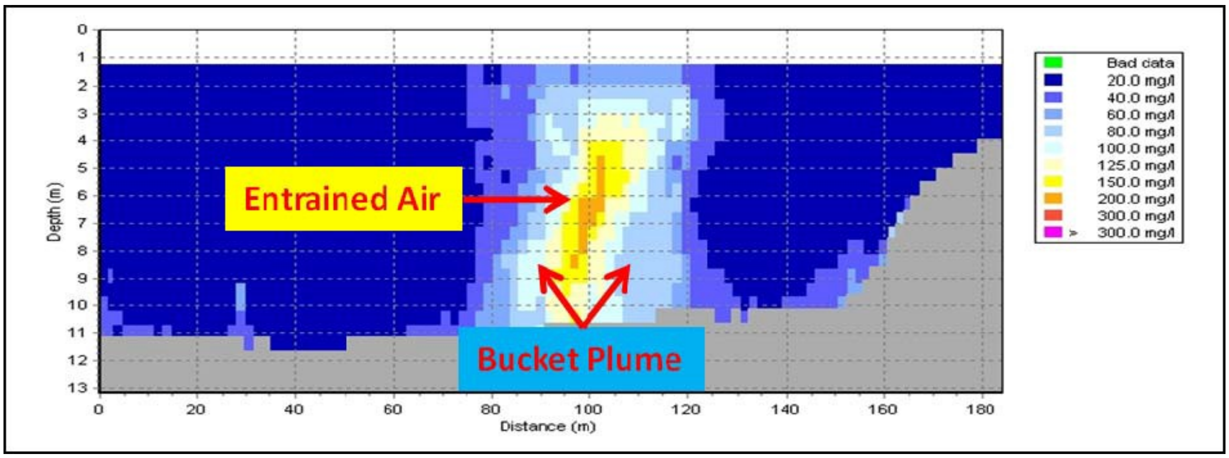
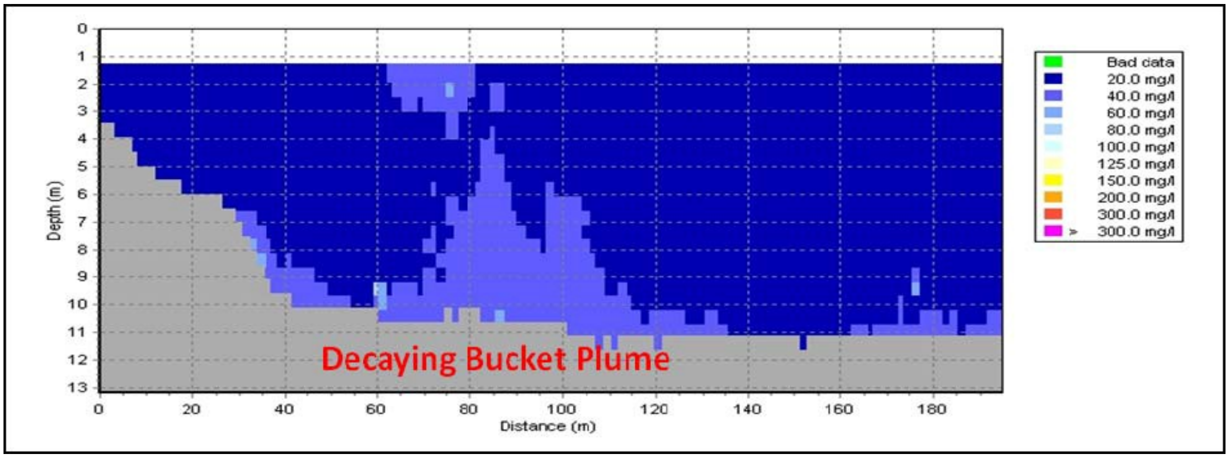


Figure 24 (RSB 18) shows significant decay of the plume generated by the bucket over a span of 45 m (total distance from the dredging operation is 95 m). Given the slow current velocities present at the study site, some of the entrained air would have dissipated. Slow flow velocities also contribute greatly to the settling process of the resuspended sediment, inducing rapid decay of the plume. At this distance, the plume still occupied the majority of the water column, although the somewhat detached plume occupying the upper 3 m of the water column is most likely entrained air. TSS concentrations throughout the plume structure are less than 40 mg/L, exceeding ambient by less than 20 mg/L. There was no evidence of a plume generated by the decanting process.

Figure 24 (RSB-18). Transect occupied 95 m from the dredge shows the rapid decay of the plume from 50 m to 95 m from the source. Some air is entrained in the upper 3 m of the water column. No decanting plume was detected. TSS concentrations exceeded ambient by < 20 mg/L.



Figures 25 through 27 (RSB 19 through RSB-21) occupied at distances from 141 m to 230 m show a diffuse plume along the channel bottom occupying the lower 1 to 2 m of the water column. The final transect in the survey (Figure 28, Transect RSB-22) at a distance of 296 m from the dredging operation shows no evidence of elevated TSS concentrations associated with the dredge plume. All TSS concentrations estimated from the ADCP vertical profile fall within background levels. Currents again were too weak to carry the plume substantial distances.

Figure 25 (RSB-19). Transect occupied 141 m downstream from the dredging operation. Only a faint plume signature is detected within the lower 2 m of the channel bottom, with the exception of a small area of increased TSS along the toe of the channel side slope. Transect heading is 160°.

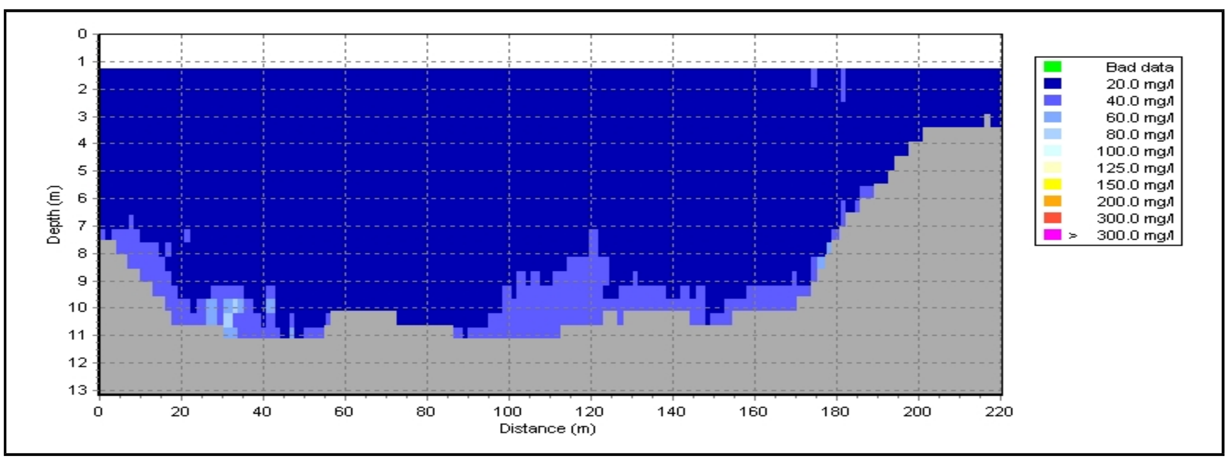


Figure 26. (RSB-20). Transect occupied 192 m (Heading = 0°) from the dredging operation. A faint plume signature is located along the center of profile associated with the excavation process. A faint residual plume signature is located along the far right side of the vertical profile. TSS concentrations were less than 20 mg/L above ambient conditions.

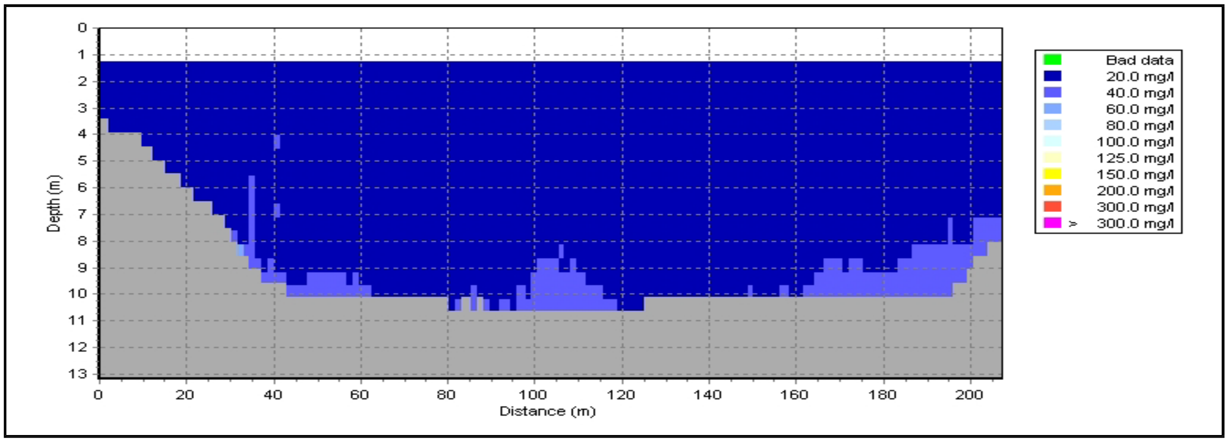


Figure 27. (RSB-21). Transect occupied 230 m downstream from the dredging operation. Transect runs in a southerly direction at 160°.

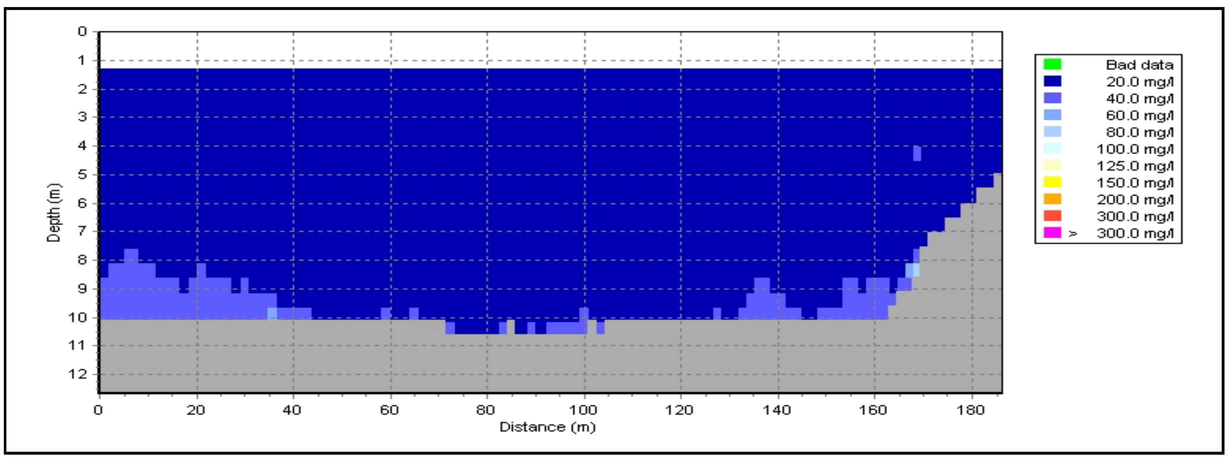
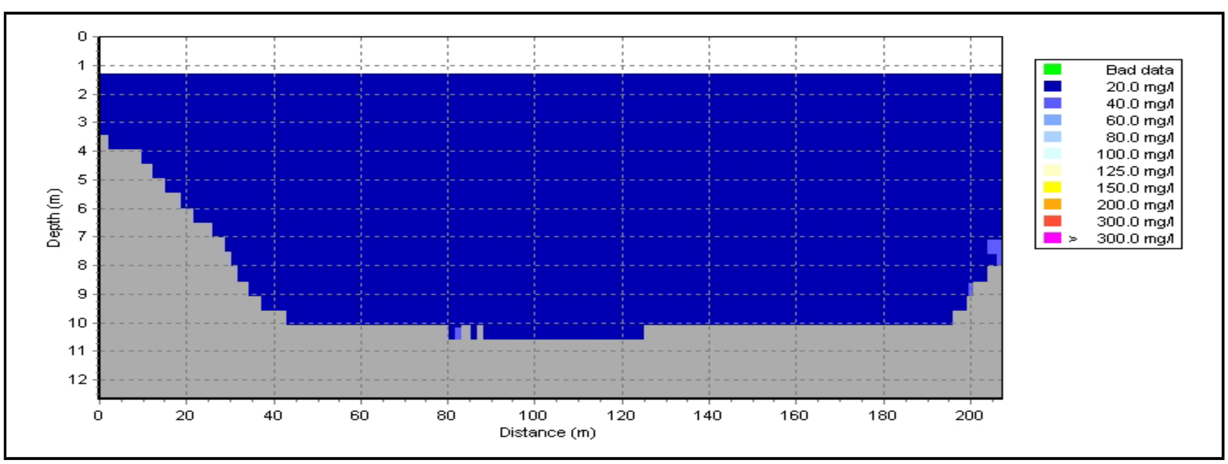


Figure 28 (RSB-22). Transect occupied 296 m downstream from the dredging operation. No evidence of the dredge or a decanting plume detected at this distance from the source. Transect runs in a northerly direction at 160°.



5 Sediment Loss and Suspended Solids Resulting from Decanting: A Modeling Approach

Water Content

The bucket captures both sediment and water; the proportions of each are a function of sediment density, the bucket design, and the dredging operation. Typically, buckets contain 10 to 30% water during production dredging and 30 to 50% water during cleanup activities. The water fraction is larger for dense sediment, which leads to partial cuts; and for light, enclosed buckets, which tend to make partial cuts and are subject to poor bucket drainage.

Dredged Material Characteristics

The dredged material mostly retains the properties of the sediment; however, a fraction of the captured water will be entrained into the captured sediment. Likewise, a fraction of the sediment will be dispersed in the captured water. A limited number of samples were collected in Richmond, CA, from a nearly full barge with the decanting standpipe open to quantify the characteristics of the barge contents. The barge contents consisted of a thin layer (ranging from 0 to 3 in.) of turbid water on the surface, a thin layer (about 6 in.) of consolidating settled solids, and a thick layer (10 to 12 ft) of consolidated sediment at relatively low bulk density. The samples were analyzed for solids concentration. The TSS concentration of the turbid water ranged from 350 to 1080 mg/L (sediment was slightly disturbed during sampling due to shallow water depth); and as high as 15,100 mg/L when the sediment was highly disturbed during the sampling process. The consolidating settled solids layer had TSS concentrations ranging from 94 to 236 g/L. The deep sediment layer had a concentration of about 410 g/L about 18 in. below the surface.

Settling Analysis

The settling characteristics of the consolidating settled solid samples were measured in a small-scale settling test. The findings were consistent with the dredged material characteristics measured in the barge as described above. The supernatant had a solids concentration of 122 mg/L after 1 hr of settling; 46 mg/L after 2 hr of settling; and 27 mg/L after 4 hr of settling. These results are consistent with the turbid water characteristics measured in the barge where the supernatant was as high as 1080 mg/L (likely overestimated), but the settling time was much less than an hour. The settled solids had a concentration of 168 g/L after 2 hr and 214 g/L after 24 hr of settling and consolidating. The projected concentration of the settled solids after a year of consolidation was 420 g/L, a level very similar to that of the deep sediment concentration: 410 g/L in the barge.

Overflow Characteristics

The decanted supernatant should resemble turbid water, having a TSS concentration of less than 1000 mg/L, unless significant scouring occurs. Scouring of consolidating settled salt water dredged material slurries has been studied for overflow through sharp-crested weir structures comparable to the barge standpipe (Walski and Schroeder 1978). The authors concluded that no scouring should occur as long as the depth of water is greater than 2 ft and only limited scouring should occur as long as the depth of water is greater than 1 ft. Predicted decanted TSS concentrations are given below as a function of water depth for a production rate of 8 cubic yd per minute, requiring a head of nearly 3 in. above the standpipe to produce a discharge rate equal to the production rate (Table 1).

Table 1. Correlation of water depth and TSS concentration.

Water Depth (inches)	TSS Concentration (g/L)
3	8
6	3.5
9	2
12	1
15	0.7
>18	0.4

Overflow Losses

Conservatively assuming the bucket contains 1/3 water and 2/3 sediment, the barge fill depth is 12 ft and the sediment concentration is 410 g/L, representative discharge losses are given in the Table 2 below.

Table 2. Predicted sediment loss from decanting

Sediment Height (ft)	Overflow Water (ft)	Sediment Conc. (g/L)	Overflow Conc. (g/L)	Percent Loss
0 to 10.5	5.25	410	0.4	0.05%
10.5 to 11	0.25	410	0.7	0.09%
11 to 11.5	0.25	410	2.3	0.27%
11.5 to 12	0.25	410	8.0	0.98%
		Barge Average	0.8	0.10%

Significance

Losses from a typical mechanical dredge ranges from 0.5 to 1%, perhaps 1 to 2% for sediment having a density as low as measured at Richmond (Palermo et al. 2008). Overflow would increase losses no more than 0.1% (no more than about 10% compared to losses without overflow). Overflow would increase capacity 50%, while increases losses no more than only 10%. Limiting overflow to a sediment fill depth one foot below the height of the overflow standpipe would increase losses no more than 5%. These are conservative predictions; actual loss rates may be less than half of these rates but overflow would likely increase project sediment loss rates by 5 to 10% as compared to project loss rates without overflow.

Suspended Solids Plume

The decanted supernatant discharges from the bottom of the barge. The decanted water should form an intermittent discharge (Richmond protocol) over the last third of the fill cycle (several hours). The intermittent plume should be quite small due to the low flow rate, and the discharge's low TSS concentration. The plume should not be visible from the surface, as seen in the current study, since it forms below the barge. Based on the USACE DREDGE dispersion model results, the turbidity plume would be rapidly dispersed to below 5 mg/L TSS in 50 m and below 2 mg/L in 100 m. The plume from decanting the full barge (Oakland protocol) may last from 20 to 30 min, but would only have elevated TSS concentrations during the last 5 to 10 min due to some possible sediment resuspension at the water-sediment interface. As discharge nears completion, the plume from the final discharge of water would be expected to disperse to below 5 mg/L TSS in 150 m and below 2 mg/L in 300 m.

6 Discussion

Overflow Process and Decanting Methodologies: Similar Concept, Different Results

Overflow is a method commonly used by Trailing Hopper Suction Dredgers (TSHD) to increase the amount of sediment loaded into the hopper of a dredge by continuing to dredge after the hopper is full. The sediment slurry is picked up by the draghead and transported through the hydraulic suction line and deposited into the hopper. As material is pumped into the hopper, a layer of high-density settled material is formed in the lower portion of the hopper with a layer of sediment-laden water in the upper portion of the hopper. As the hopper approaches maximum capacity, excess water and sediment are discharged in a process known as "overflow." The overflow process is essential to interpretation of sediment resuspension in the water column. Capacity in terms of hopper volume and pumping rates determine the dredging cycle; i.e., the time necessary to fill the hopper to the point of overflow and the effective duration of overflow. To a certain extent, the configuration of the hopper and the "weir" used to control overflow govern the properties of the supernatant slurry discharged back to the water column. Note that the term "overflow" is a misnomer derived from early generations of hopper dredges and barges in which the supernatant was allowed to run over the gunnels of the hopper. Consequently, the discharge occurred directly into surface waters. The industry standard, including both the Dredge *Yaquina* and Dredge *Essayons*, for example, now employs vertical tubular weirs that discharge the supernatant slurry through the bottom of the hull. Thus, a more appropriate term would be "underflow." This is important in assessing the dynamics of the generated plumes. Because overflow does not start until the hopper is filled to the height of the weir, the dredge has been loaded to nearly full draft before overflow begins. In the case of the Dredge *Yaquina*, this means that the discharge occurs below the hull at a depth of approximately 15 ft (Dickerson et al. 2005). The effluent also is injected into the water as a downward vertical density jet, which tends to take the resuspended solids toward the bottom. Forward motion of the vessel creates a shear that deflects some of the injected sediment laterally, and turbulence of the vessel passage and associated prop wash can draw a portion of the effluent higher into the water column. In a study by Dickerson et al. (2005), overflow plumes generated by the Dredge *Yaquina* were monitored in Humboldt Bay, California. The authors concluded, based on the acoustic signature of plumes detected by an ADCP, that the overflow plume was directed downward and that a rapid separation of the plume from the prop wash signatures was noted. There did not appear to be a significant degree of upward mixing of the plume as influenced by vessel movement.

An additional feature installed on the Dredge *Essayons* is an "Anti-turbidity Value." In Europe, where the technology originated, the value is often called an "environmental value." The valve does not appreciably reduce the absolute mass of sediment inserted in the water column, although it can be used to maximize settlement within the hopper such that a slightly higher retention of fines can be achieved. The main function of the valve is to remove air from the discharge (Ofuji et al. 1977). Air in the discharge tends to create a buoyant plume; i.e., the rising air bubbles in the effluent carry sediment particles higher in the water column. By removing air out of the discharge, the density jet more effectively tasks the sediment suspension deeper into the water column and facilitates settlement. Importantly, one must realize that the absolute mass of sediment in the discharge would not be appreciably reduced, but simply redirected.

Another aspect of hopper dredge plume dynamics that may be further clarified by understanding the process is the perception that the mass of sediment injected into the water column is higher per unit volume of water. Use of the term "overflow" connotes a very dense plume. Certainly the discharge jet can contain high concentrations of solids. However, the portion of the high density jet that is stripped off to create the passively drifting plume is (1) a fraction of the injected sediment mass and (2) a diluted portion as a consequence of the continuous forward motion of the point of discharge. The maximum concentrations observed in the passively drifting hopper dredge plume are determined by the composition of sediment in the discharge and the interaction of those particles with hydrodynamic forces and settlement processes. The fractions of fines stripped away from the jet would be subjected to flocculation and enhanced settlement as occurs in a saline environment. Rates of decay of plumes observed in the Humboldt overflow plume monitoring study as well as other plume characterizations undertaken by ERDC are consistent with settlement of relatively dilute suspension of fines.

The different decanting protocols used in mechanical dredging operations are unlikely to have a substantial effect on the amount of sediment released, although this would need to be quantified by further study. In one protocol, the standpipe was left open continuously (Richmond). After approximately 18 hr of barge loading, sediment and water had reached near the “lip” of the standpipe. While the initial water placed into the barge had nearly 18 hr to settle before release, the settling process did not occur undisturbed in that additional bucketloads of material created a small wave and ripple effect, which resuspended some portion of the sediment. The intermittent discharge of water carried some of this resuspended sediment out through the standpipe, although the release sediment was not significant in that the discharge could not be detected by the ADCP even at the closest distance in which transects could be occupied at the dredge and barge. Once the barge was filled to capacity, the remaining portion of the decant water, given its shallow depth, had sufficient time to settle, resulting in a low flow of nearly clear water discharged through the standpipe. Following the alternate protocol (Oakland methodology), the standpipe valve would remain closed for the duration of dredging. After the scow had been filled to the allowable level, the decant water would be allowed to settle for one hour, after which the scupper valve would be opened and the supernatant water discharged as a single 20-minute event. Most of the water discharged would be relatively clear due to the intervening settling time, although a small amount of sediment may be eroded from the water-sediment interface and released due to higher flow velocities associated with the single discharge protocol. The protocol at Richmond provided for a slower flow velocity, but the fine sediment particles in the decant water would have a comparatively short time to settle before discharge.

Key differences between overflow from TSHD and barge decanting are (1) decanting attempts to minimize the release of suspended sediments by allowing time for resuspended sediments to fall out of suspension; (2) releasing only small amount of sediment-laden water at any given time produces — at best — a small plume with very diluted TSS concentrations; (3) a single release over the course of many hours (Oakland methodology) as opposed to unrestricted during overflow; and (4) the limited spatial extent in which TSS concentrations can be detected above background. In the current study, the decanted water produced a plume of such limited spatial extent that it remained under the barge and therefore was not detected during any of the ADCP surveys. While there are several factors that determine the down-current movement of a plume detectable above background concentrations, the process of discharging small quantities of excess water across the duration (multiple hours, and in the case of the current study 24 hours) of the barge-filling process contributed to a very small, highly diluted plume, confined to the immediate vicinity of the mechanical dredging operation. As the barge was nearing full capacity, successive bucketloads placed towards the bow of the barge would cause a small wave of decant water to breach the lip of the standpipe and be discharged. A video showing the wave forming as the bucket placed material into the scow can be seen in Video IMG-1909. These small wave discharges occurred on approximately a 1-2 min time interval, producing a short-lived discharge that started with a higher flow rate, then decreasing as the wave of water discharged through the standpipe (See Video MVI 3694). The rate of discharge decreased substantially by mid-point (the later 30 sec to 1 min of the cycle) — slowing down to little more than a trickle — before the next wave was produced. After the scow had been filled to the maximum allowable fill level, the remaining water slowly drained from the barge. During this time period, the resuspended sediment fell out of suspension to the point where the decant water became relatively clear. This is illustrated in Video IMG 2038. While overflow, as used by TSHD, attempts to force settling by removing air, the amount of sediment released is typically not reduced.

In the case of other dredging projects using the Oakland methodology, the discharge of excess water can occur as a single event typically lasting for approximately 20 min. This event only occurs after the water in the barge has had a minimum of one hour to allow for settlement. Most of the water discharged would be relatively clear due to the intervening settling time, although a small amount of sediment may be eroded from the water-sediment interface and released due to higher flow velocities associated with the single discharge protocol. The protocol at Richmond provided for a slower discharge flow velocity, but the fine sediment particles in the decant water would have a comparatively short time to settle before discharge. Even if the plume was detectable using the Oakland protocol, the single event occurring over a 24-hour barge filling time frame would have no significant impact on biological resources in the area. In contrast, during hydraulic dredging, the plume generated during overflow is unrestricted and is nearly constant over the entire overflowing process and can be detected along the entire length the vessel has traveled, increasing the overall spatial extent of the plume detectable above background.

However, given the use of tubular weirs and anti-turbidity values, the plume is typically confined to the lower portion of the water column, and undergoes fairly rapid settling and is highly diluted in terms of TSS concentrations. The different decanting protocols are unlikely to have a substantial effect on the amount of sediment released, although this would need to be quantified by further study.

Given that no distinct, measureable plumes were detected from the decanting process in the current study, plumes generated by the bucket can provide some insight about the dredging operation as conducted at Richmond Harbor. It worth noting, however, that both surveys occurred during an ebbing tide, which further complicated the attempt to measure TSS concentrations in the decanting discharge due to orientation of the dredge and barge. The standpipe was located at the rear of the barge scow. During the ebb tide, current movement was in a westerly direction. Any plume generated during decanting would first have to travel beneath the entire length of the barge and/or dredge before emerging from the bow and/or possibly the starboard or port side of the scow (depending on dredge orientation). Any decanting discharge plume would then likely merge with the plume generated by the bucket actions and would not, in most cases, be detectable as a separate plume. Considering the rate of settling (low current velocities enhance settling) of the plume generated by the bucket, concentrations from the emerging decanting discharge plume would be so low to render them indistinguishable from the bucket plume. A decanting discharge plume that did emerge would be in the near-field, along with the plume generated by the bucket. TSS plumes generated by the bucket/ sediment removal were not detected beyond 230 m from the dredging operation. The portion of the detected plume containing substantial TSS concentrations above ambient was limited to less than 75 m from the source, indicating rapid decay due to low current velocities. Beyond 125 m, TSS concentrations generated by the bucket exceeded ambient by less than 20 mg/L and occupied only a small portion of the lower water column (lowest 1 m of the water column). The overall limited spatial extent and low TSS concentration gradient structure indicated that even the sediment removal process as conducted at Richmond Harbor produces a plume that would not have negatively impacted aquatic biological resources in the area, especially when considering the bucket plume would be expected to be several orders of magnitude greater in terms of both TSS concentrations and spatial extent when compared to the decant plume.

It is possible that a slightly better chance to map the decanting plume would have occurred during a flooding tide, when net current flow was in an easterly direction. Under this scenario, the overflow plume would still have had to travel beneath the dredge and scow but for a much shorter distance before emerging astern of the dredge. Based on the observed rapid decay of the bucket plume, if the decant plume was detected, it would be a very small signature of extremely limited spatial and temporal scales of low TSS concentrations.

Video 1. Video showing the generation of a small wave of water moving towards the back of the scow.

Video 2. Video showing the wave generated by the placement of material into the scow breaching the lip of the standpipe during decanting discharge. This discharge rate continues for approximately 15 to 30 seconds before the decant water falls below the “lip” of the standpipe. Flow velocity decreased significantly before the next wave was generated as additional material is released into the scow.

Video 3. This video shows fairly clear water overflowing the standpipe. After the barge has reached 80% capacity, the remaining water in the scow, in a thin supernatant layer, slowly moved to the rear of the scow and out the standpipe.

7 Conclusion

The dredging process as conducted in the current study produced a well-defined bucket plume of limited temporal and spatial extent. Narrow bands of elevated TSS concentrations (actual TSS values minus entrained air are likely between 100-125 mg/L to less than 30 m from the point source) associated primarily with sediment excavation. The elevated TSS remained confined within the navigation channel; no evidence of plume transport out of the confines of the channel side slopes was observed or detected. Sediment loss that was associated with the decanting discharge remained confined beneath the dredge and scow and was not detected or observed by the field crew. All TSS values were derived from plumes generated by the bucket and not the decanting process.

Based on barge sampling, sedimentation analysis, and decant analysis, decanting would increase the overall sediment loss by no more than 10% (as compared to sediment loss without decanting) or about as much as 0.1% of the sediment solids dredged. Typically, about 1% of the sediment is lost during sediment excavation by mechanical dredging, somewhat more for low density sediments as in the case of Richmond Harbor. Decanting increases barge capacity by as much as 50%, greatly reducing the dredging time, air emissions, and required trips to the placement site. Eliminating decanting would increase dredging, transport, and placement costs by as much as 40%. These are conservative predictions; actual loss rates may be less than half of these rates.

Species of concern (e.g., anadromous fishes) would experience fairly low TSS concentration exposures in the immediate vicinity (< 100 m) of the dredging operation and in the case of Richmond Harbor only within the navigation channel since there was no evidence of plume movement outside of the channel proper. Assuming that mobile or drifting organisms were present, exposures to suspended sediments would be very short term, as plumes decayed to nearly background levels in 10 to 15 min after the dredged stopped production. Ambient TSS concentrations in the study area were as high as 20 mg/L. The zone of influence primarily in the direction of current flow would conservatively be between 75 to 200 m wide and extending down-current to 75 m (small traces of the decayed plume were detected to slightly less than 150 m from the point of excavation). Sediment loss that was associated with the decanting discharge remained confined beneath the dredge and scow. All TSS values were derived from plumes generated by the bucket and not the decanting process. Given that the "true" value (minus entrained air) is likely not to exceed 100 to 125 mg/L, these concentrations would be well below that which would have any harmful effects on fish egg development, larval stages or adults as reported in a comprehensive review by Wilber and Clarke (2001). The effects of suspended sediments on a variety of fish species have been evaluated by Sherk (1972) and Sherk et al. (1974; 1975), Auld and Schubel (1978), Boehlert and Morgan (1985), Wilber and Clarke (2001), and Suedel et al. (2012). Most fish species showed no negative effects other than sublethal or behavioral responses at TSS concentration below 200 mg/L.

SAV occurs outside of the channel; consequently, no exposure would occur if the plume remained confined to the navigation channel. With regards to SAV (eelgrass), TSS plumes and turbidity based on USACE DREDGE dispersion model results would rapidly disperse to below 5 mg/L within 50 m and below 2 mg/L in 100 m. Neither concentration would be sufficient to produce negative impacts to the growth and survivability of eelgrass.

In conclusion, the barge decanting process as conducted at Richmond did not inject sufficient quantities of suspended sediment into the water column to be detectable beyond the confines of the dredge and barge, and, if merged with the bucket plume, did not appear to appreciably increase the TSS concentrations evident in the barge decanting process that plume. It is unlikely that decanting using either of the two methodologies described in this paper would contribute significantly to loss of material back into the water column.

References

Auld, A. H., and J. R. Schubel. 1978. Effects of suspended sediment on fish eggs and larvae: A laboratory assessment. *Estuarine and Coastal Marine Science* 6: 153-164.

Blott, S. J. and K. Pye. 2001. GRADISTAT: A grain size distribution and statistics package for the analysis of unconsolidated sediments. *Earth Surface Processes and Landforms* 26: 1237-1248.

Boehlert, G. W., and J. B. Morgan. 1985. Turbidity enhances feeding abilities of larval pacific herring. *Clupea harengus pallasi. Hydrobiologia* 123: 161-170.

Bohlen, W. F., D. F. Cundy, and J. M. Tramontano, 1979. Suspended material distribution in the water of estuarine channel dredging operations. *Estuarine and Coastal Marine Science* 9: 699-711.

Dickerson, C., D. Clarke, and K. Reine. 2005. *Monitoring hopper dredge overflow plumes in Humboldt Bay, California*. Data report submitted to the U.S. Army Corps of Engineers San Francisco District.

Folk, R. L. 1968. *Petrology of sedimentary rocks*. Hemphills, University of Texas, Austin, TX.

Folk, R. L. and W. C. Ward, 1957. Brazos River bar: A study in the significance of grain size parameters. *Journal of Sedimentary Petrology* 27: 3-26.

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

Ofuji, I., S. Waseda, and N. Ishimatsu. 1977: Anti-turbidity overflow system for a hopper dredger. *IHI Engineering Review 10:61-68*.

Palermo, M. R., and R. E. Randall. 1989. Practices and Problems Associated with Economic Loading and Overflow of Dredge Hoppers and Scows. In *Proceedings of the WODCON XII, Dredging: Technology, Environmental, Mining, 2-5 May 1989*. World Dredging Congress, Orlando, FL.

Palermo, M. R., P. R. Schroeder, T. J. Estes, , and N. R. Francingues. 2008. *Technical Guidelines for Environmental Dredging of Contaminated Sediments*. ERDC/EL TR-08-29. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Plumb, R. H. 1981. Procedures for handling and chemical analysis of sediment and water samples. US Environmental Protection Agency and US Army Corps of Engineers Technical Committee on Criteria for Dredged Material. Technical Report EPA/USACE 81-1. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

RD Instruments (RDI). 2003. Optimizing Your ADCP Setup—Technical Note: TN032. http://www.rdiinstruments.com/tips/tips_archive/tips_pdfs/RDI_TechTipOptADCPSetup.pdf

Reine, K. J., D. G. Clarke, and C. Dickerson. 2002. *Acoustic characterization of suspended sediment plumes resulting from barge overflow*. DOER Technical Notes Collection. ERDC TN-DOER-E-15. Vicksburg, MS: U.S. Army Engineer Research and Development Center. www.wes.army.mil/el/dots/doer

Sherk, J. A. 1972. Current status of the knowledge of the biological effects of suspended and deposited sediments in Chesapeake Bay. *Chesapeake Science* 13: 137-144.

Sherk, J. A., J. M. O'Conner, and D. A. Neumann. 1975. Effects of suspended and deposited sediments on estuarine environments. In *Estuarine Research 2*, ed. L.E. Cronin, 541-558. New York, NY: Academic Press.

Sherk, J. A., J. M. O'Conner, D. A. Neumann, R. D. Prince, and K. V. Wood. 1974. "Effects of suspended and deposited sediments on estuarine organisms, Phase II," Reference No. 74-20, Natural Resources Institute. College Parke, MD: University of Maryland.

Suedel, B., C. Lutz, J. Clarke, and D. Clarke. 2012. The effects of suspended sediment on walleye (Sander vitreus) eggs. *Journal of Soils and Sediments* 12:995-1003.

Tavolaro J. F. 1984. A sediment budget study of clamshell dredging and ocean disposal activities in the New York Bight. *Environmental Geology and Water Science. Vol. 6, No. 3.*

USACE. 2001. Providence River and harbor maintenance dredging project: Environmental impact statement. Prepared by the U.S. Army Corps of Engineers New England District, Concord, MA.

Unified Facilities Guide Specifications, Waterway and Marine Construction, Division 35, Section 35 20 23, Paragraph 3.2.6.1.1 (April 2006) http://www.wbdg.org/ccb/browse_cat.php?c=3

Walski, T. M. and P. R. Schroeder. 1978. *Weir design to maintain effluent quality from dredged material containment areas*. Technical Report D 78 18. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Wilber, D. H. and D. G. Clarke. 2001. Biological effects of suspended sediments: A review of suspended sediment impacts on fish and shellfish with relation to dredging activities in estuaries. *North American Journal of Fisheries Management* 21(4):855-875.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE ***(DD-MM-YYYY)*** June 2015	**2. REPORT TYPE**	**3. DATES COVERED** ***(From - To)***

4. TITLE AND SUBTITLE

Characterization of Suspended Sediment Plumes Resulting from Barge Decanting in San Francisco Bay

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Kevin J. Reine and Paul R. Schroeder

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER

ERDC/EL TR-15-5

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Corps of Engineers
Washington, DC 20314-1000

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The San Francisco Bay Regional Water Quality Control Board (SFRWQB) and the U.S. Environmental Protection Agency (USEPA) are seeking to prohibit barge decanting during dredging operations. The agencies cite environmental concerns associated with the release of suspended sediments as the primary justification for banning the barge decanting activities. Since approximately 40% to 70% of the volume placed in the scow is water, this will create budgetary cost overruns for future projects. Transporting this volume of water (124 miles round trip) rather than sediment would significantly impact the efficiency and cost of conducting dredging. Projected cost increases without decanting could be more than 40%. To assess potential impacts from barge decanting, acoustic surveys using a 600 kHz acoustic doppler current profiler (ADCP) were conducted to (1) determine the total suspended solids (TSS) concentration above ambient for plumes produced by both barge decanting and buckets associated with mechanical dredging; (2) determine the TSS of the supernatant water during barge loading, after the settling period and during the decanting process as water passes through the standpipe; and (3) determine the percent of dry mass of sediment loss back to the water column as a result of decanting. Results indicated that no distinct, separate, identifiable plume signature associated with barge decanting was detected by ADCP. Based on calculations of TSS from the supernatant discharge, decanting would increase losses by no more than 0.1%. Decanting would, however, increase the effective loading capacity by as much as 50%.

15. SUBJECT TERMS

Navigation Dredging	Suspended Sediment Plumes	Supernatant Discharge
Decanting	Overflow	
	Acoustic Doppler Current Profiler	

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** ***(include area code)***
Unclassified	Unclassified	Unclassified		53	