PRELIMINARY ASSESSMENT OF SEDIMENT RESUSPENSION BY SHIP TRAFFIC IN NEWARK BAY, NEW JERSEY

D. Clarke[1], C. Dickerson[2], K. Reine[3], S. Zappala[4], R. Pinzon[5] and J. Gallo[6]

ABSTRACT

One of the most frequently cited environmental concerns linked to potential detrimental impacts of dredging projects is sediment resuspension, either during the dredging itself or as a consequence of open-water dredged material disposal. Justifications for a majority of environmental windows placed on dredging projects refer to potential exposures of aquatic organisms to resuspended sediment either during dispersion in the water column or upon re-deposition to the bed. However, very few attempts have been made to place dredging-induced resuspension into perspective with other natural (e.g., tidal flows, high riverine discharges, storm wind and wave forces) or anthropogenic (e.g., commercial or recreational vessel traffic passage and maneuvering) sources of resuspension. Accurate assessments of impacts of dredging should involve determination of the increment of sediment mass inserted into the water column by dredging as compared to these other sources. Characterization of the spatial scales and temporal dynamics of dredging-induced resuspension alone severely constrains such assessments. Whether or not dredging represents a meaningful increment above background conditions in terms of spatial extent, dose (concentration integrated through time), or frequency of exposure can only be determined when other components of the sediment resuspension budget within a waterway are known. The present study examines suspended sediment plumes created by various types of vessels within Newark Bay, New Jersey, a highly industrialized estuary that comprises a portion of the greater New York/New Jersey Harbor complex. Navigation infrastructure in Newark Bay accommodates frequent deep draft vessel arrivals and departures on a daily basis. Plumes were characterized using methodologies similar to those routinely used to monitor dredge plumes. Spatial scales, total suspended solids (TSS) concentration gradients, and dispersion patterns were measured by a combination of mobile acoustic Doppler current profiler (ADCP) surveys and collection of water samples for gravimetric analysis. Plumes associated with ship traffic varied substantially among type (e.g., deep draft container ship versus shallow draft barge/tug) and movement pattern (e.g., container ship under power or maneuvering with assistance of tug tenders, passage in open-water versus docking at berths). Very large, prominent plumes initially extending from the surface to the bottom were primarily associated with turning maneuvers of deep draft vessels at the entrance to secondary berth access channels. Plumes rapidly dissipated in the upper portion of the water column, but persisted at depth for relatively long periods. TSS concentrations above 90 mg/l were found over broad areas following vessel maneuvers. Often bottom plumes remained detectable against ambient conditions throughout the time intervals between successive arrivals and departures, persisting for at least 50 minutes in open-waters where tidal currents could disperse plumes, and indefinitely in secondary channels where current flows were comparatively slow. Residual plumes in the lower 2 m of the water column with TSS concentrations of 40 mg/l or less were detectable at the point of deep draft vessel passage for at least 65 minutes. In contrast, little evidence was seen of bottom disturbance and resuspension by shallow draft barge/tug traffic. Results indicate that deep draft vessel use of the navigation channels does measurably contribute to the overall sediment resuspension budget within Newark Bay. Results are discussed in relation to dredging and natural estuarine processes, emphasizing that these sources of resuspension act in tandem, but on different temporal and spatial scales, to affect patterns of water column TSS and sedimentation rates. Assessments of dredging impacts without reference to these processes can result in misleading conclusions.

Keywords: Plume, deep draft, turbidity, navigation

[1] U.S. Army Engineer Research and Development Center, 3909 Halls Ferry Road, Vicksburg, MS 39180, Douglas.G.Clarke@erdc.usace.army.mil
[2] Bowhead Information Technology Services, 1905B Mission 66, Vicksburg, MS 39180
[3] U.S. Army Engineer Research and Development Center, 3909 Halls Ferry Road, Vicksburg, MS 39180.
[4] HDR/LMS, One Blue Hill Plaza, Pearl River, NY 10965.
[5] U.S. Army Engineer New York District, 26 Federal Plaza, New York, NY 10278.
[6] U.S. Army Engineer New York District, 26 Federal Plaza, New York, NY 10278.

INTRODUCTION

Many of the environmental concerns that arise in connection with navigation dredging projects are linked to sediment resuspension. A major premise is that dredging can place a sufficient mass of sediment into suspension on spatial and temporal scales that can cause detrimental effects on organisms or their habitats. Although a great deal of effort has been made historically to characterize and quantify sediment resuspension by various dredge types in a wide variety of settings, relatively little effort has been directed at other sources of resuspension that contribute to the overall sediment resuspension budget in a given waterway, harbor, or estuary. Few attempts have been made to evaluate other natural or anthropogenic sources of resuspension (e.g., Renger and Bednarczyk 1986; Fredette et al. 1988; Erdmann et al. 1994; Ruffin 1998; de Madron et al. 2005; Ferre et al. 2005; Dellapenna et al. 2006; Lohrer et al. 2006) or specifically to place dredging into perspective with other sources (Bohlen 1980; Sosnowski 1984; Pennekamp et al. 1991; Schoellhamer 1996, 2002). In particular, resuspension due to deep draft vessel traffic has seldom been considered in tandem with dredging, although the two are intimately linked to maintenance of navigation infrastructure.

Newark Bay experiences a high frequency of deep draft vessel traffic on a daily basis. The extent of sediment resuspension attributable to this traffic is unknown, but may be significant (Figure 1). The present study represents a preliminary effort to determine the scales and dynamics of ship-induced sediment resuspension in Newark Bay, New Jersey. During the course of navigation dredging monitoring activities, opportunities arose to examine the resuspension characteristics of several vessels arriving and departing from the Port of Elizabeth and the Port of Newark. These results are intended to lay the groundwork for design and execution of dedicated field efforts to monitor suspended sediment plumes associated with ship traffic.

Figure 1. Aerial photograph of Port Elizabeth, New Jersey. Note the prominent plume behind the container ship that has entered the Elizabeth Channel stern first (at the upper right) and the container ship moving north along the eastern berthing areas (right side). An operating dredge is also visible at the entrance to the Elizabeth Channel. (Image courtesy of the Port Authority of New York and New Jersey)

METHODS

Plumes were surveyed with an acoustic Doppler current profiler (ADCP) using methods consistent with those described in detail in a companion paper in these proceedings (see Clarke et al. 2007) describing monitoring of dredge plumes in the Arthur Kill Waterway. Because the surveys described herein were completed during unanticipated periods of dredge inactivity, dedicated surveys of ambient conditions were not conducted. However, ambient data were collected in the same sections of the navigation channels during ADCP surveys of current patterns of the Port Elizabeth Harbor complex. A single transect is exemplified in Figure 2, which was located in the same location as the first series of ship resuspension surveys. On this transect the upper half of the water column had TSS concentrations in the 10 to 30 mg/l range. Concentrations were higher in the lower portion of the water column, with a thin layer of up to 60 mg/l just above the bottom. These conditions may represent a residual plume from an earlier ship passage.

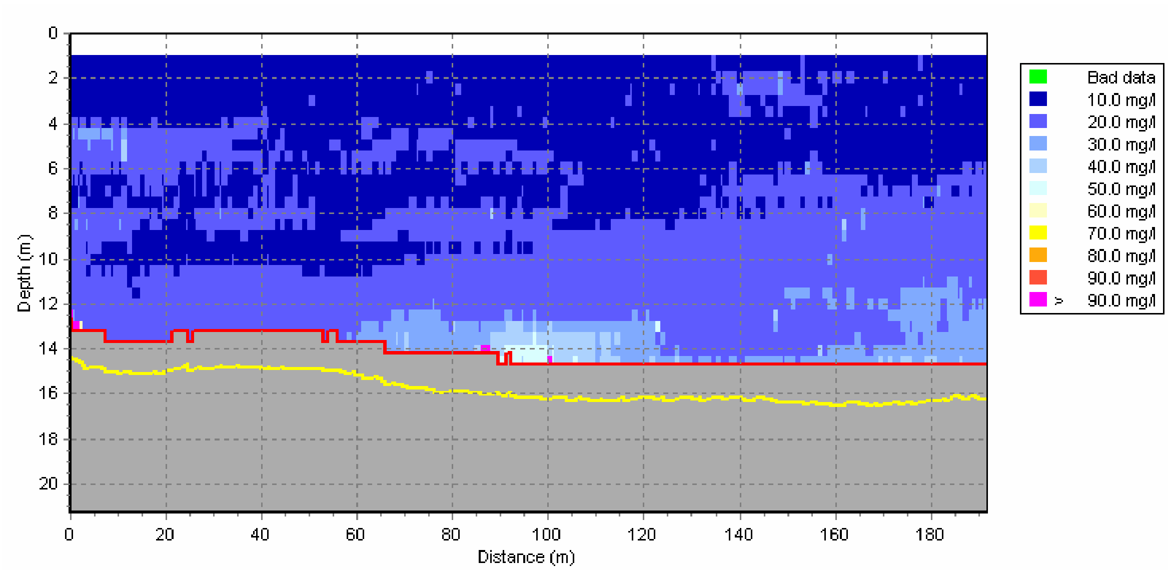

Figure 2. Ambient TSS concentrations across a transect on 6 July 2006 during a middle phase of a flooding tide. This transect location coincides with that of ensuing ship passage surveys.

Water sampling in the ship plumes was not conducted, so a dedicated data set for calibration of the ADCP for acoustic backscatter conversion to total suspended solids (TSS) concentration was not obtained. However, a calibration data set based upon water samples collected in the Port Elizabeth channels during mechanical dredging was available and applied to the ADCP data. Conversion of acoustic backscatter data to estimates of TSS concentration was accomplished by application of a calibration procedure described by Land and Bray (2000). The degree of confidence that can be placed in the estimates of concentration is proportional to the strength of the calibration data set. The quality of the calibration is in turn dependent on the collection of adequate water samples to represent sediments in suspension at all depths in the water column and across the entire gradient of concentrations occurring in ambient as well as plume waters. In this study 89 water samples, ranging in TSS concentration from 5.6 to 300 mg/l, produced an excellent calibration, although the overall number of samples at the upper end of the concentration gradient was limited. In Figure 3 the entire population of gravimetric measurements derived from water samples and acoustic estimates derived from ADCP backscatter data are arranged in rank order. A relatively strong correspondence exists between the two measures throughout the sampled range, although acoustic estimates tend to slightly overestimate concentration in the high range. Collection of high concentration samples proved to be difficult because of the very small down-current distances at which high concentrations could be found. Safety factors prevented the survey vessel from maneuvering sufficiently close to the dredge to consistently obtain such samples. Thus figures of vertical profiles through ship plumes reported herein should be viewed as estimates of TSS concentrations depicting general concentration gradient structure and not precise measurements. As in the case of dredge plumes, air entrainment in the vessel prop-wash is a significant source of acoustic energy reflection, so that acoustic signatures directly behind a vessel's passage are obviously contaminated with air. As time elapses air bubbles dissipate and truer estimates of TSS concentration are derived. With these caveats the results of the present effort are presented.

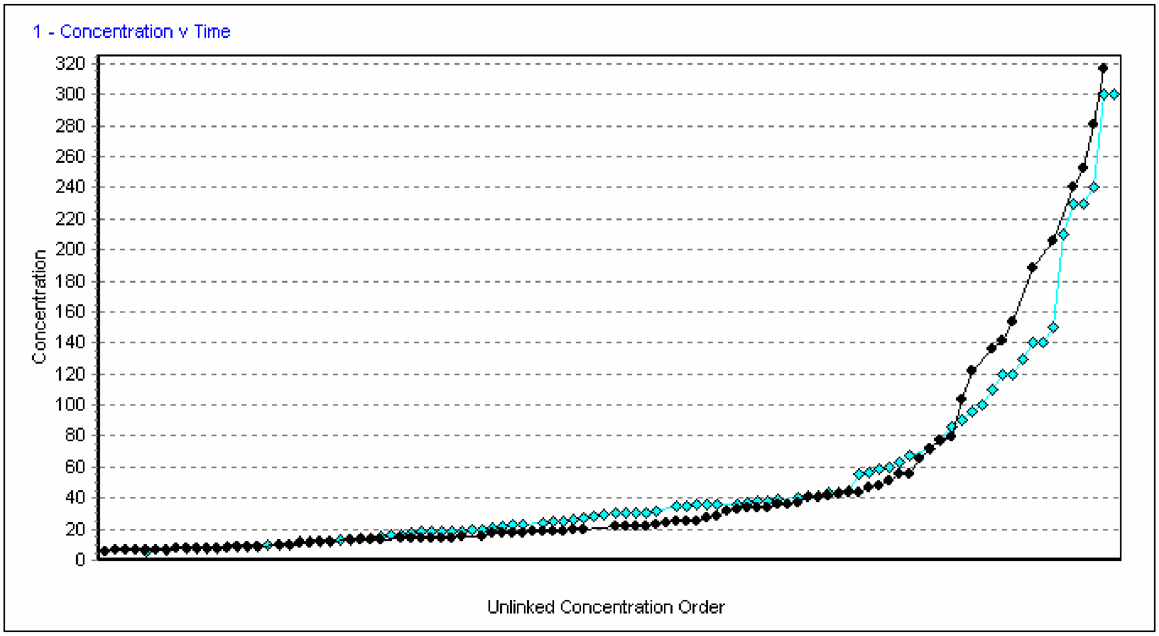

Figure 3. Comparison of gravimetric and acoustic estimates of TSS concentration for the entire population of 89 water samples in rank order. Gravimetric results are represented in blue, and acoustic estimates in black.

RESULTS

First Ship Traffic Survey Series

Ship re-suspension of bottom sediments was monitored on two separate occasions. The first survey was conducted on July 9th during slack water conditions following an ebbing tide. The Yang Ming Line container ship *YM North* progressed northward along the Newark Bay Middle Reach Channel and arrived at the outer junction with the Elizabeth Channel at approximately 1300 hrs. Assisted by tugs the vessel rotated to enter port stern first. The *YM North* then continued stern first into the Elizabeth Channel and docked. During the rotation maneuver a prominent surface plume of increased turbidity was generated (Figures 4 and 5).

Figure 4. Surface turbidity created by maneuvering the container ship *YM North*.

Figure 5. Surface turbidity created by maneuvering the container ship *YM North*.

A repetitive ADCP transect was established across the area in which the ship had turned (Figure 6), extending from the northeast corner of the Port Elizabeth Marine Terminal to the red channel marker buoy "R 14". Immediately after passage of the ship nine survey lines were completed between 1309 and 1404 hrs. The first transect (Figure 7) passed through the wake directly behind the *YM North* as close as safely possible. A significant amount of air was entrained in the water column by the ship's propeller as indicated by the intense pink areas in the figure. Although air contamination prevents TSS estimation on this transect, bottom disturbance and turbulence throughout the water column is evident. A second transect (Figure 8) was conducted approximately 6 minutes after the first transect. Most of the entrained air had dissipated upward and is seen as a distinct surface feature. A clear acoustic signature of bottom resuspension is present with concentrations greater than 90 mg/l in the lower half of the water column. A third transect (Figure 9) was completed approximately 19 minutes after the first transect. A general settling and spreading of the plume had occurred with concentrations as high as 70 to 80 mg/l near the bottom. A fourth transect (Figure 10) was conducted approximately 24 minutes after the first transect, with a TSS pattern similar to the previous transect. TSS concentrations near the bottom were as high as 90 mg/l. A fifth transect (Figure 11) was conducted approximately 29 minutes after the first transect and indicates further settling of the plume. Concentrations near the bottom were as high as 70 mg/l.

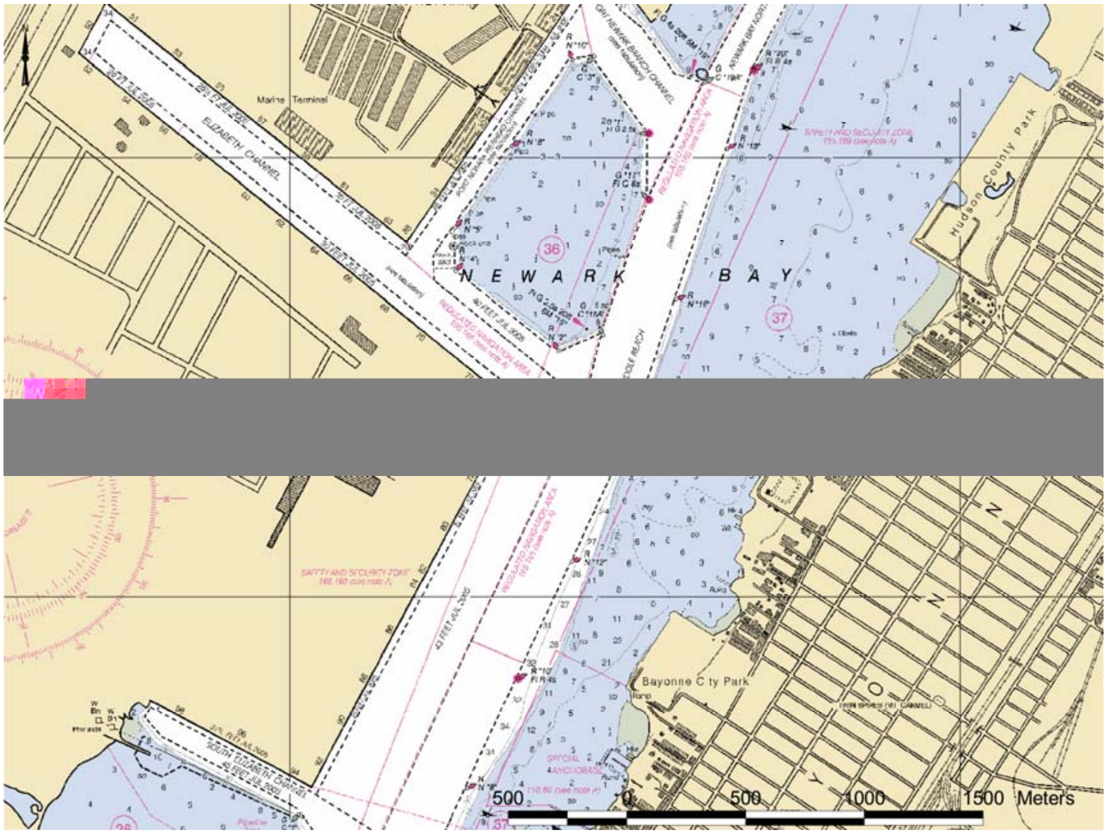

Figure 6. Repetitive transect location.

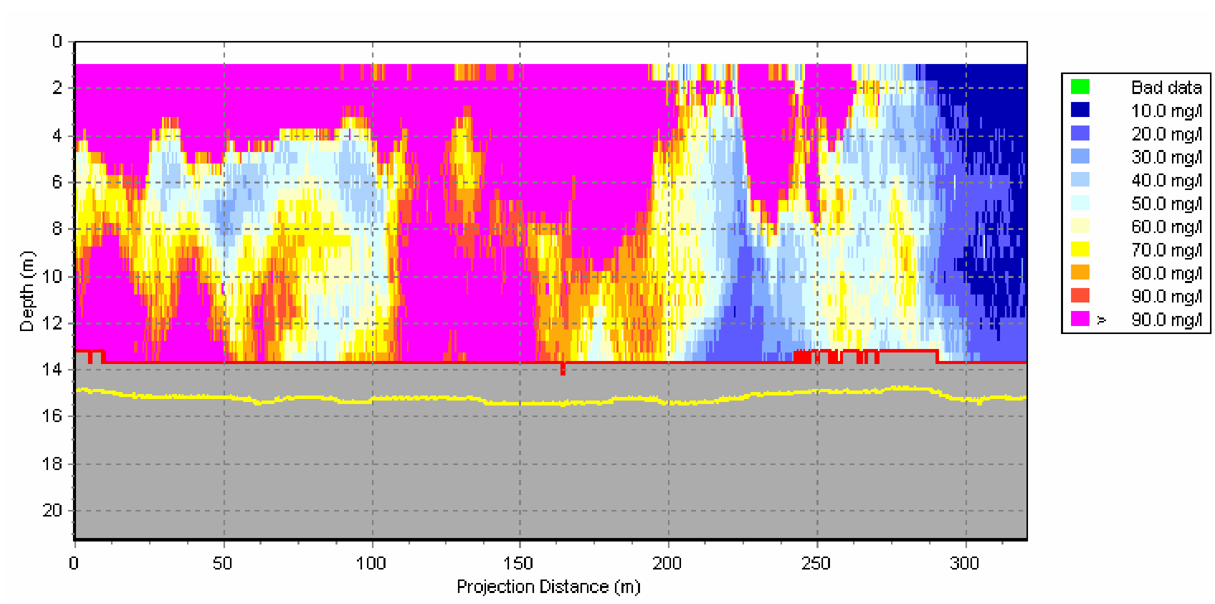

Figure 7. First transect directly behind *YM North* (Time 0).

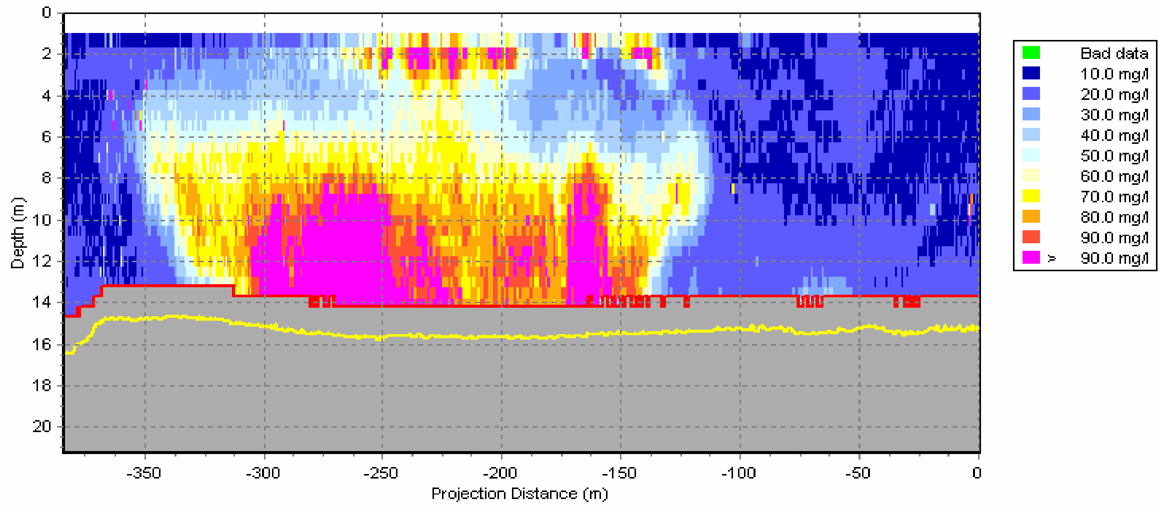

Figure 8. Second transect behind *YM North* 6 minutes after first transect.

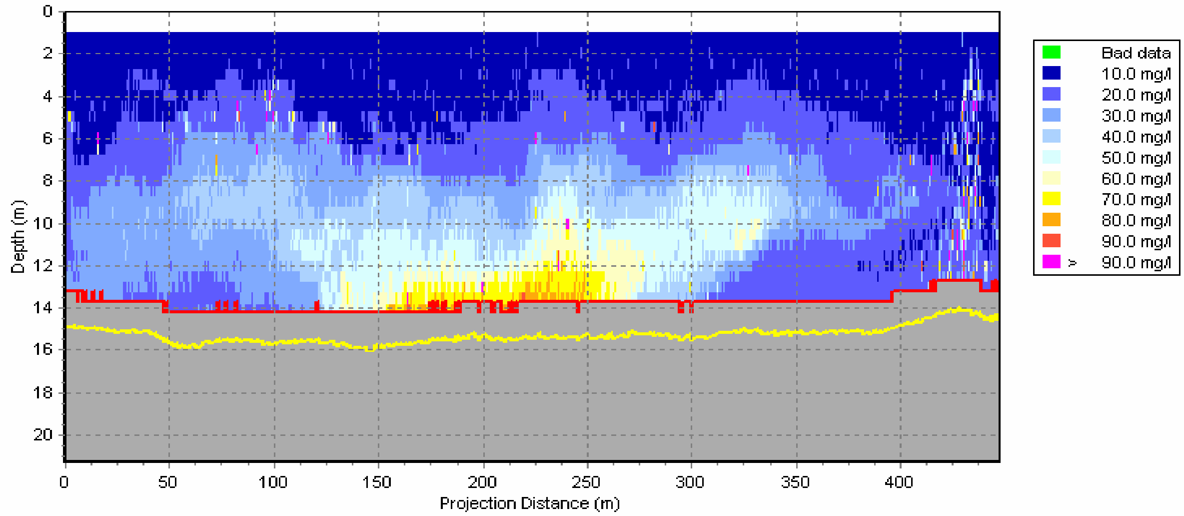

Figure 9. Third transect behind *YM North* 19 minutes after first transect.

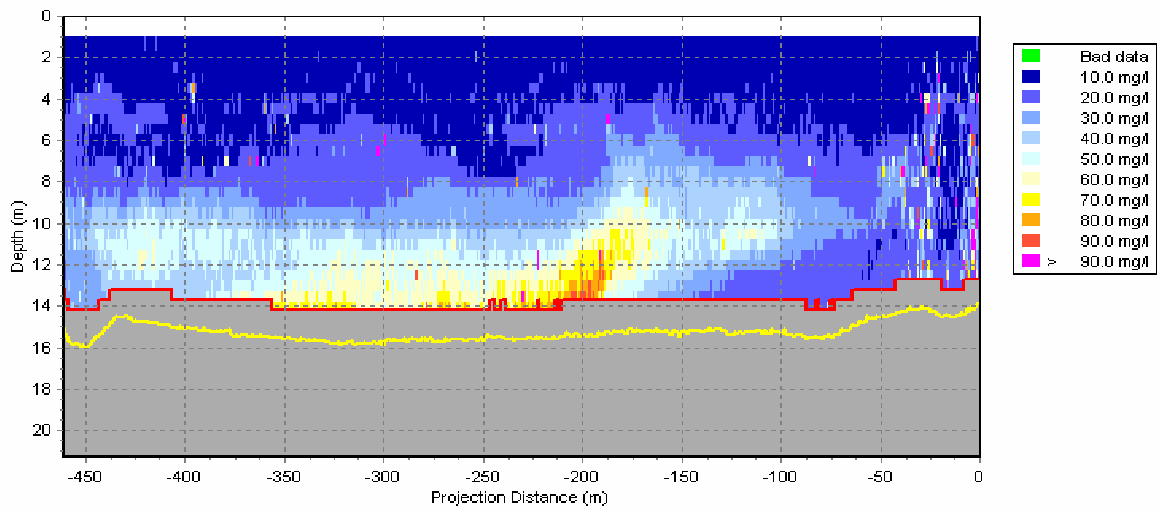

Figure 10. Fourth transect behind *YM North* 24 minutes after first transect.

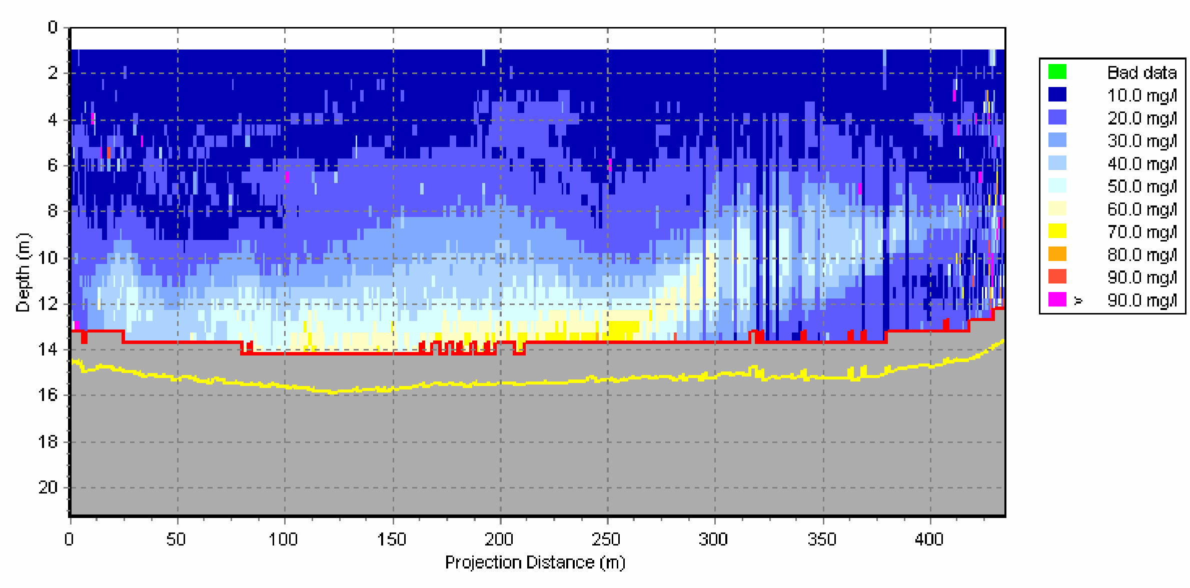

Figure 11. Fifth transect behind *YM North* 29 minutes after first transect.

At approximately 1330 hrs the car carrier ARC *Freedom* exited Port Newark and crossed the repetitive transect at approximately 1342 hrs (Figure 12). Markings on the hull of the ARC *Freedom* indicated that it had a draft of approximately 9.2 meters. Simultaneously, a tug pushing a loaded dredge barge exited Port Elizabeth and transited the area (Figure 13). Both vessels were heading southward down the Newark Bay Middle Reach Channel.

The sixth transect (Figure 14) in this series was conducted approximately 33 minutes after the first transect, crossing astern of the ARC *Freedom* as closely as possible. Air is clearly present in the wake signatures of both the ARC *Freedom* on the right and the tug and barge on the left. The wake signatures from the tug and barge indicate disturbance to a depth of approximately 6 m, whereas the car carrier's wake signature extends to a depth of approximately 12 m. Neither vessel appeared to induce appreciable resuspension of the bottom. The plume created earlier by the *YM North* is still easily detected with concentrations near the bottom still as high as 70 to 80 mg/l.

Figure 12. Car carrier ARC *Freedom* approaching repetitive transect location.

Figure 13. Tug and loaded scow crossing repetitive transect.

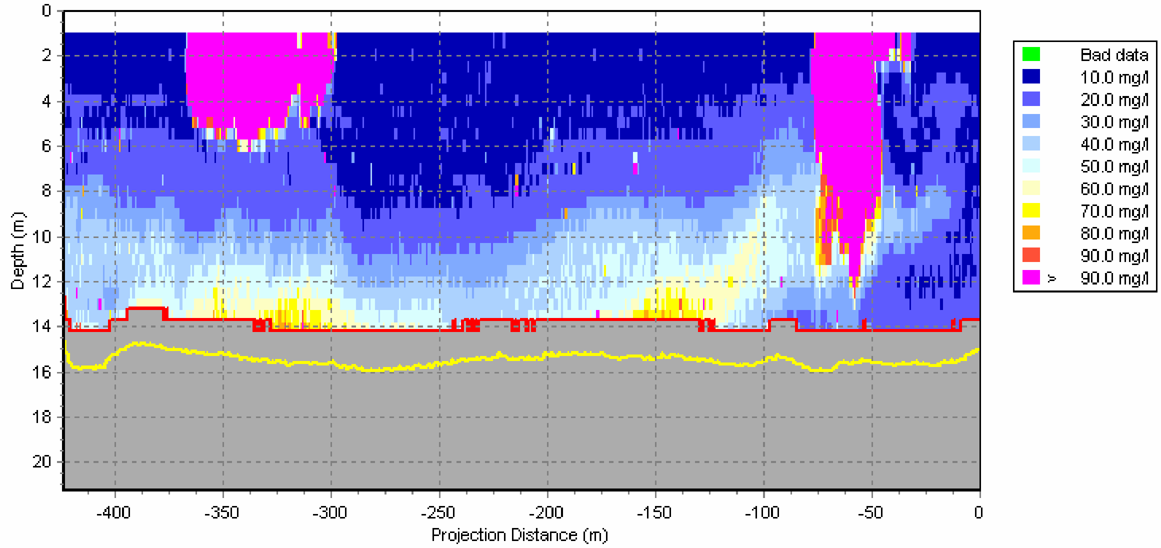

Figure 14. Sixth transect behind *YM North* 33 minutes after first transect showing ship wake signatures of a tug and barge (left) and the car carrier ARC *Freedom* (right).

A seventh transect (Figure 15) was conducted approximately 40 minutes after the first transect. The wake signature from the tug and barge persisted to a depth of approximately 6 m, however, the wake signature from the ARC *Freedom* had dissipated. Settling of the original plume continued with a few isolated patches of TSS concentrations as high as 70 mg/l. Concentrations near the bottom were now approximately 50 to 60 mg/l. The eighth transect (Figure 16) was conducted approximately 45 minutes after the first transect. Vestiges of the *YM North* plume remained near the bottom at TSS concentrations less than 60 mg/l.

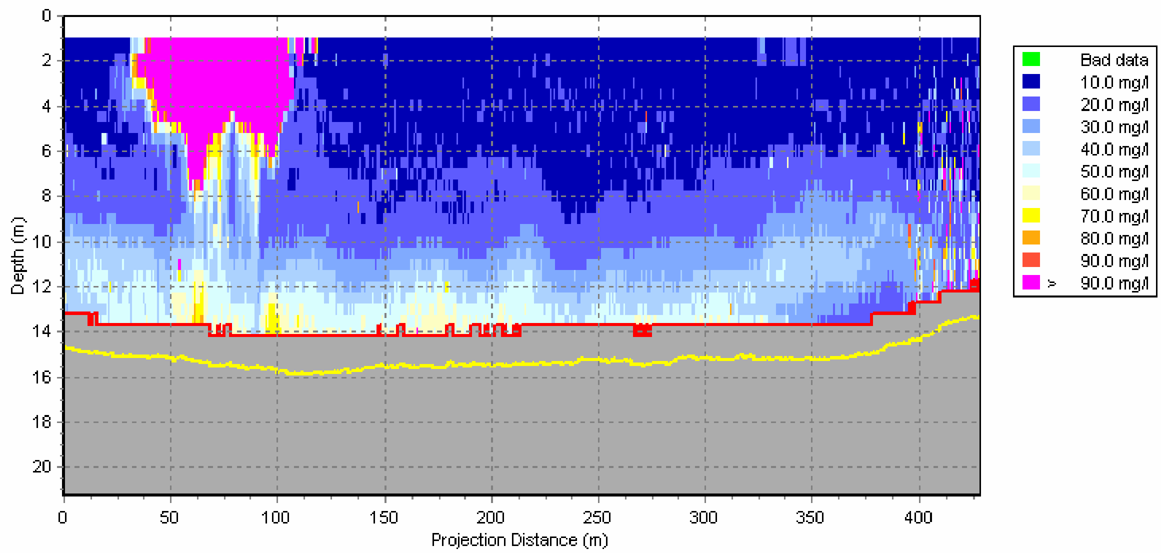

Figure 15. Seventh transect behind *YM North* 40 minutes after first transect with the wake signature of the tug and scow still visible on the left while the wake signature from the car carrier ARC *Freedom* has dissipated.

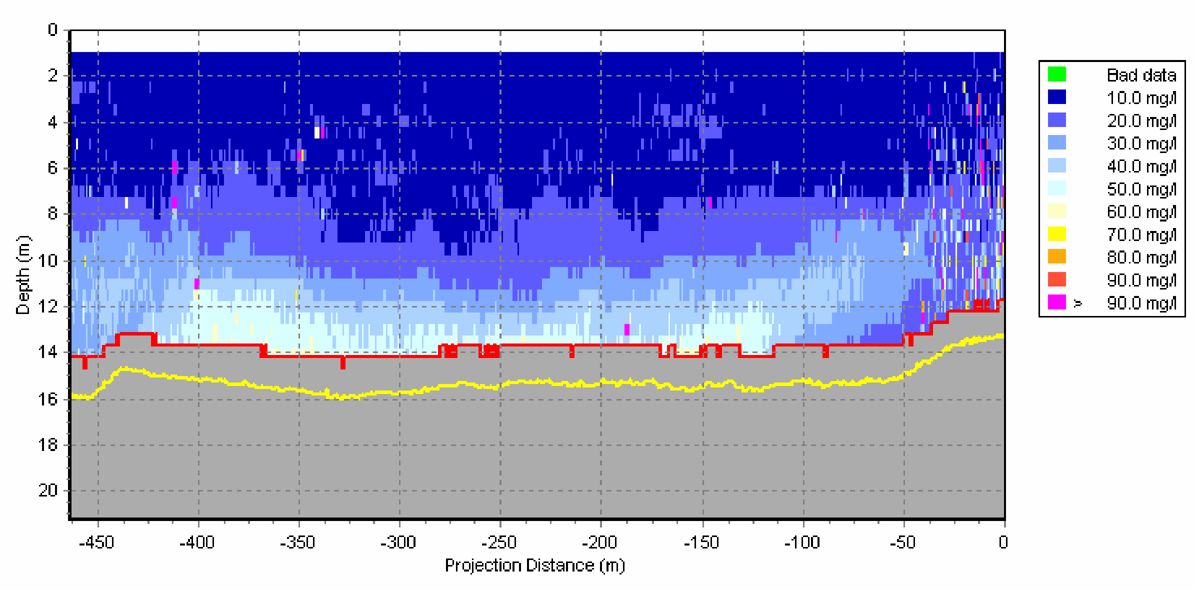

Figure 16. Eighth transect behind *YM North* 45 minutes after first transect, both wake signatures now dissipated.

Just prior to the start of the ninth and final transect of this repetitive line survey the tug *Iona McAlister* (Figure 17), which had been assisting in docking operations of the *YM North*, departed Port Elizabeth and crossed the repetitive transect line. The ninth transect (Figure 18) was conducted approximately 50 minutes after the first transect behind the *YM North* and shows the wake signature of the tug *Iona McAlister*. The re-suspension plume from the *YM North* was still visible with concentrations less than 50 mg/l near the bottom. At this point in time the ADCP survey series was terminated.

Figure 17. Tug *Iona McAlister* crossing repetitive transect.

Second Ship Traffic Survey Series

A second series of repetitive ADCP transects was conducted on July 10th during slack water conditions following an ebbing tide between 1358 and 1517 hrs. This survey consisted of 10 transects along the same path as shown in Figure 3 for the previous series. Prior to the start of the survey the container ship *Hudson* (Figure 19) entered Port

Elizabeth. An exact time that the *Hudson* transited the survey line was not available but was estimated to be less than 30 minutes prior to the start of the survey.

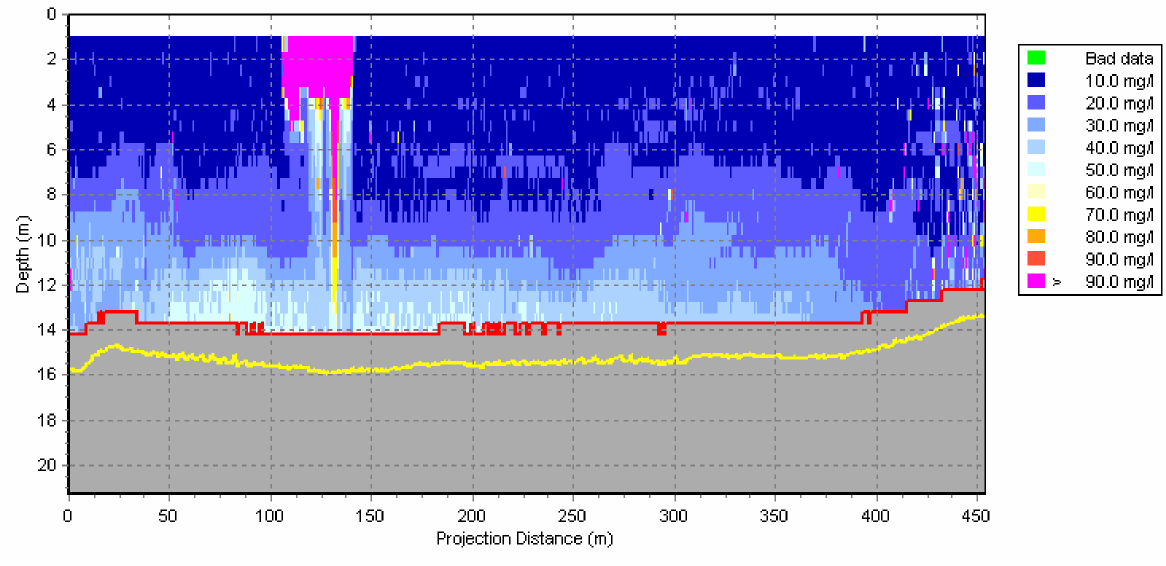

Figure 18. Ninth transect behind *YM North* 50 minutes after first transect showing wake signature of entrained air from tug boat *Iona McAlister*.

Figure 19. Container ship CMA CGM *Hudson* docked prior to second survey.

A pre-passage transect (Figure 20) was conducted just prior to the arrival of the container ship CSCL *Melbourne* (Figure 21). Note that due to the presence of residual plume from the recent passage of the *Hudson* this transect does not depict true “ambient” conditions. Unlike the maneuvering of the *YM North* which used the outer portion of the Port Elizabeth Channel to turn and enter Port Elizabeth stern first, the *Melbourne* simply turned directly into the Port Elizabeth Channel and proceeded to the dock. The *Melbourne* did create a prominent surface turbidity plume.

The first transect (Figure 22) of this series passed immediately behind the *Melbourne*. The wake signature from the *Melbourne* (on the left side of the profile) indicates disturbance of the water column from the surface to the bottom. The acoustic signature of the residual plume from the *Hudson* is also still distinct on the right of the figure. A second transect (Figure 23) was run approximately 4 minutes after the first transect and detected significant disturbance of the bottom (on the left side of the profile) while the residual plume from the *Hudson* remained intact (on the right). A third transect (Figure 24) was completed approximately 9 minutes after the first transect, revealing TSS concentrations as high as 90 mg/l near the bottom associated with passage of the *Melbourne*. The two separate plumes from the *Hudson* and the *Melbourne* began to merge into a single diffuse plume at this point. A fourth transect (Figure 25) was run approximately 13 minutes after the first transect. The two plumes were now completely merged into a single plume. TSS concentrations remaining attributable to the *Melbourne* ranged as high as 70 mg/l in one isolated area near the bottom. The fifth transect (Figure 26) was occupied approximately 18 minutes after the first transect, detecting continued dissipation of the overall plume. TSS concentrations attained a maximum of 50 mg/l or less. A sixth transect (Figure 27), conducted approximately 23 minutes after the first transect, showed further decay and settlement of the plume with TSS concentrations generally 40 mg/l or less with a few isolated areas of about 50 mg/l. A seventh transect (Figure 28), conducted approximately 26 minutes after the first transect, showed little change from the previous transect.

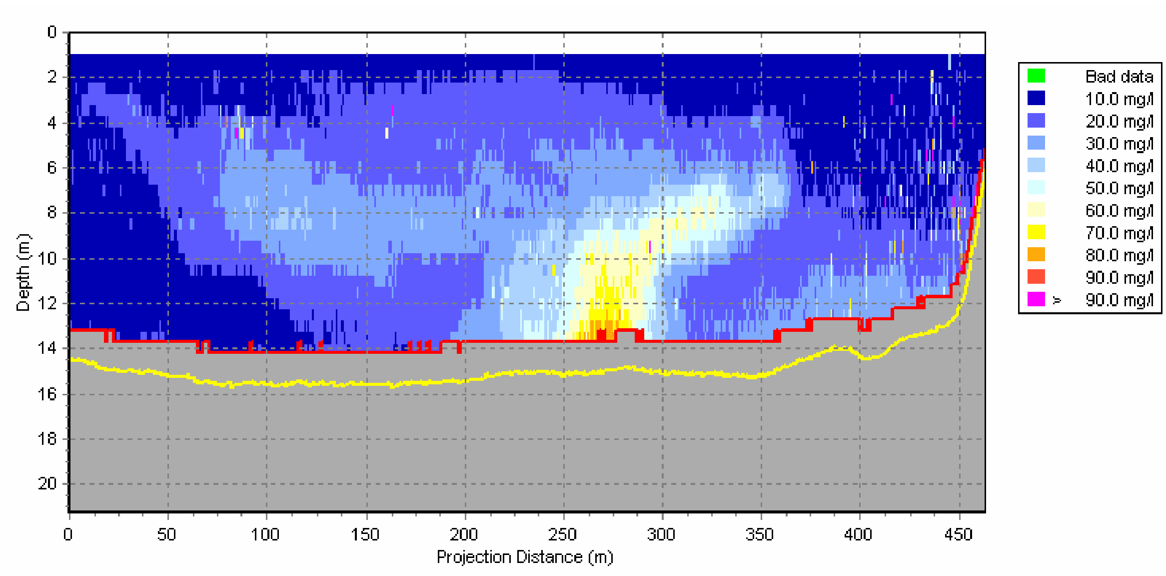

Figure 20. Residual plume from container ship CMA CGM *Hudson*.

Figure 21. Container ship CSCL *Melbourne* in the Newark Bay Channel.

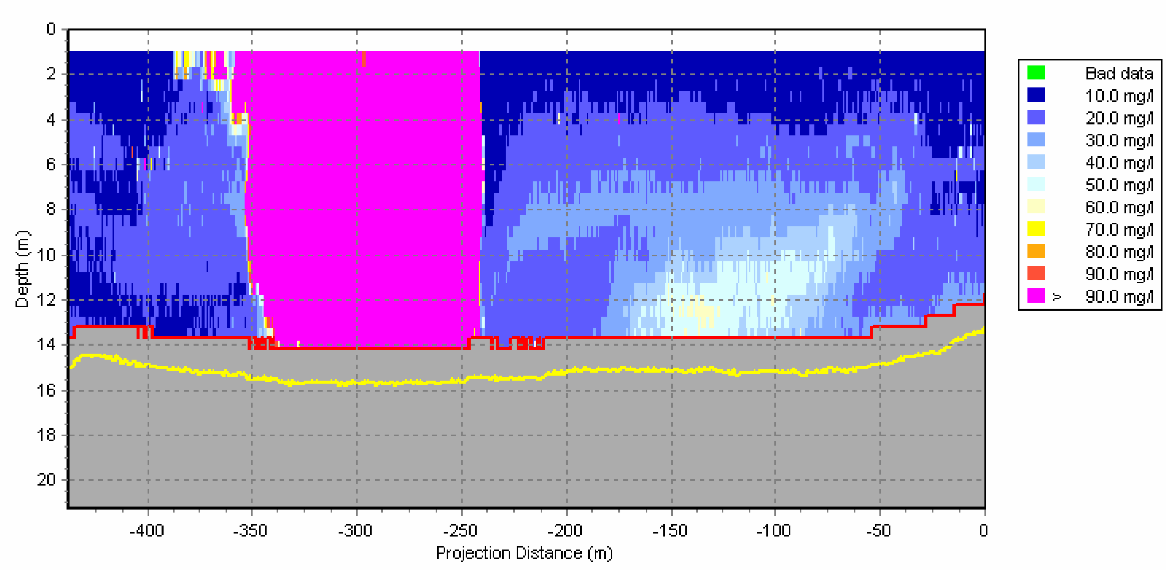

Figure 22. First transect directly behind the *Melbourne* (Time 0). The wake signature of the *Melbourne* is clearly visible on the left extending from the water surface to the bottom. The residual plume from the *Hudson* is still visible on the right.

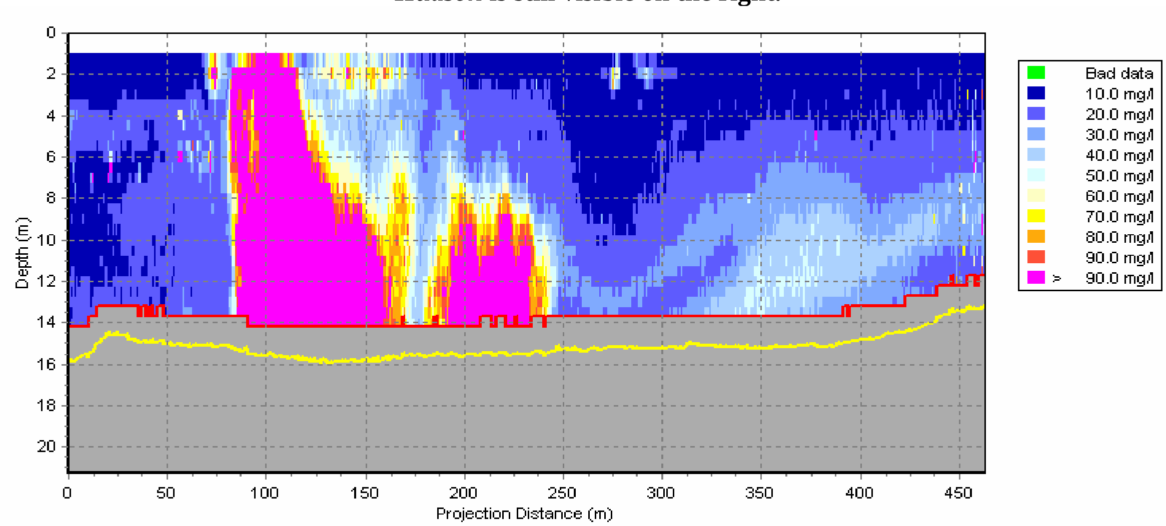

Figure 23. Second transect behind the *Melbourne* 4 minutes after first transect.

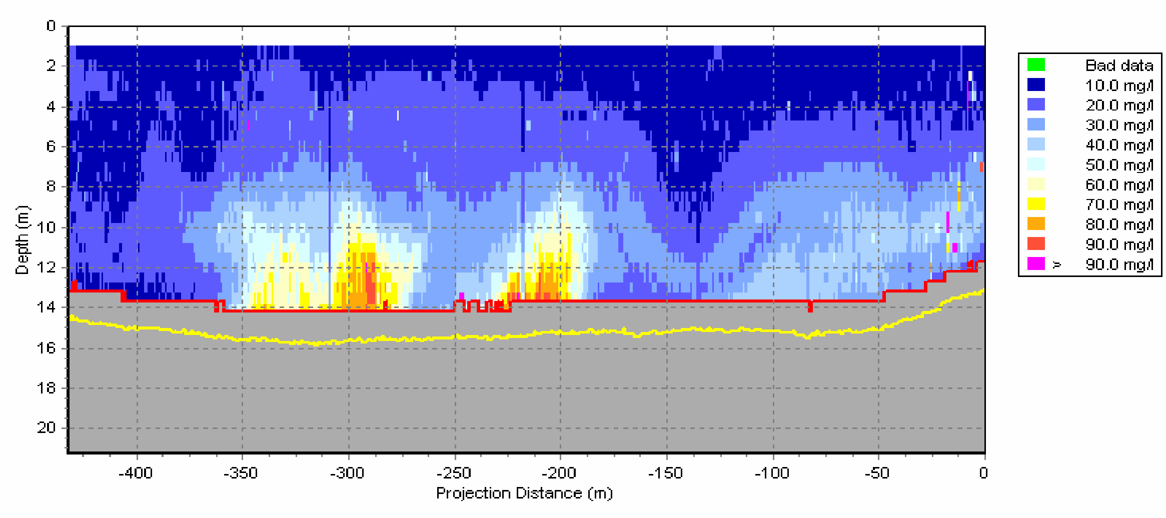

Figure 24. Third transect behind the *Melbourne* 9 minutes after first transect.

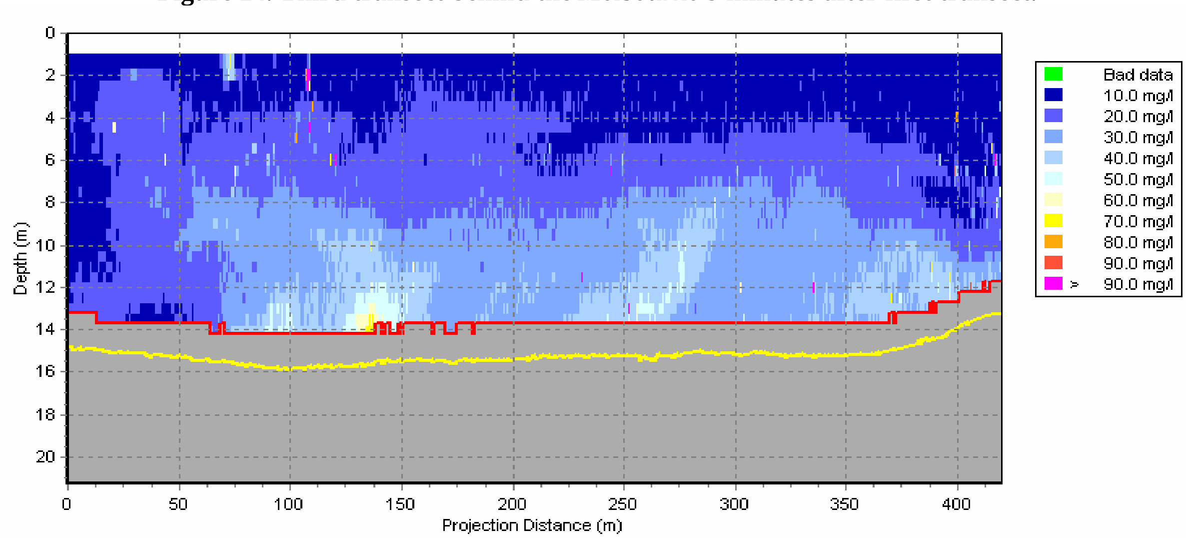

Figure 25. Fourth transect behind the *Melbourne* 13 minutes after first transect.

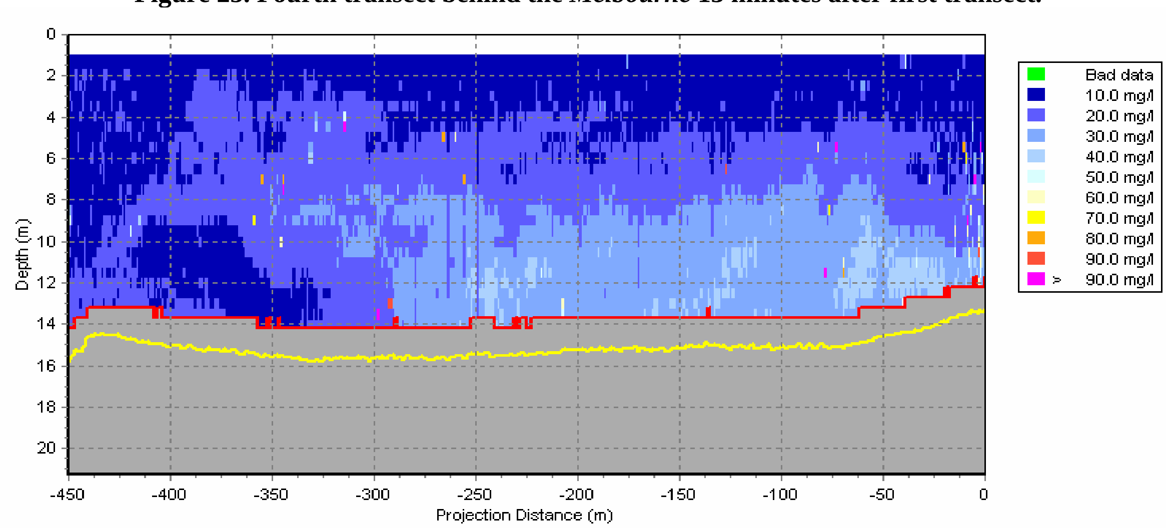

Figure 26. Fifth transect behind the *Melbourne* 18 minutes after first transect.

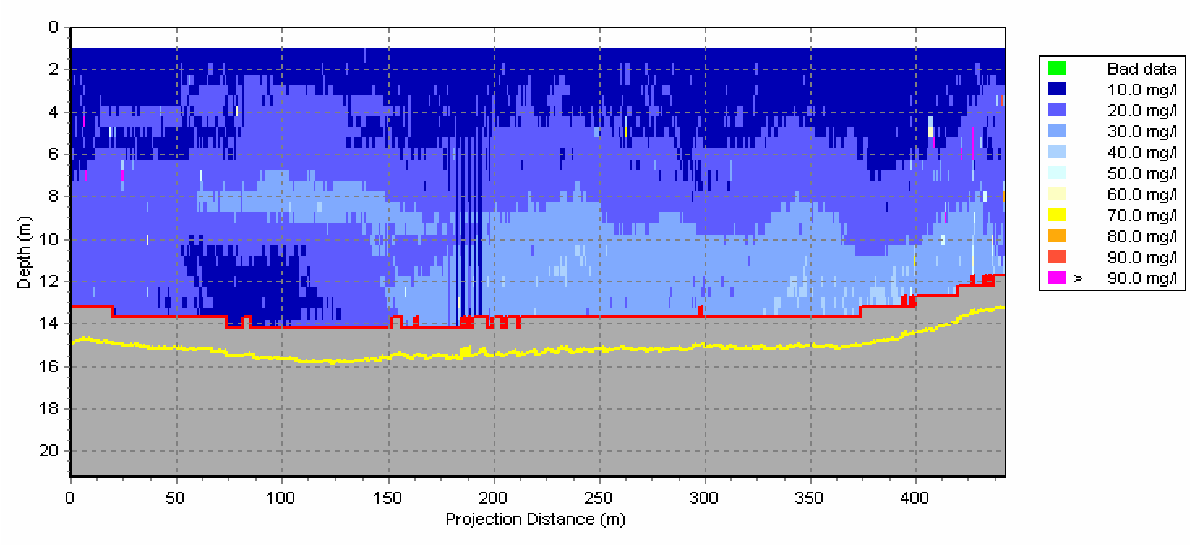

Figure 27. Sixth transect behind the *Melbourne* 23 minutes after first transect.

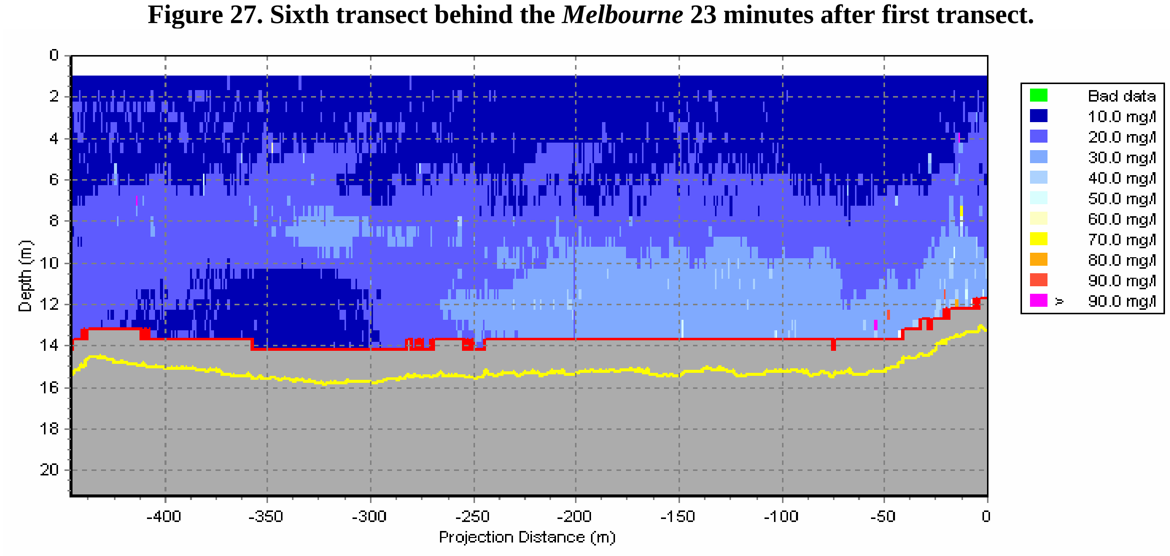

Figure 28. Seventh transect behind the *Melbourne* 26 minutes after first transect.

At 1436 hrs the survey was temporarily suspended while the survey vessel went into Port Elizabeth to obtain information about the draft and registry of the container ships *Hudson* and *Melbourne*. The Hudson was observed to draft 10 m at the bow and 10.5 m at the stern. The Melbourne was observed to draft 12 meters at the bow and 12.5 meters mid-ship.

An eighth transect (Figure 29) was re-established approximately 58 minutes after the first transect. Substantial settling and dissipation of the plume had occurred in the intervening time period. The residual plume had almost completely settled to within 2 m of the bottom with concentrations almost entirely less than 40 mg/l. The ninth and final transect (Figure 30) was completed approximately 1 hour and 5 minutes after the first transect. Just prior to the start of the ninth transect a large tug exited Port Elizabeth and transited the survey location resulting in the wake signature observed on the left side of the profile. Similar to the previous transect's profile, the plume has now settled to just off the bottom and decayed considerably in concentration. At this point in time the survey series was terminated. Notably, despite current lows, the residual plume along the same transect persisted for over 1 hr following ship passage.

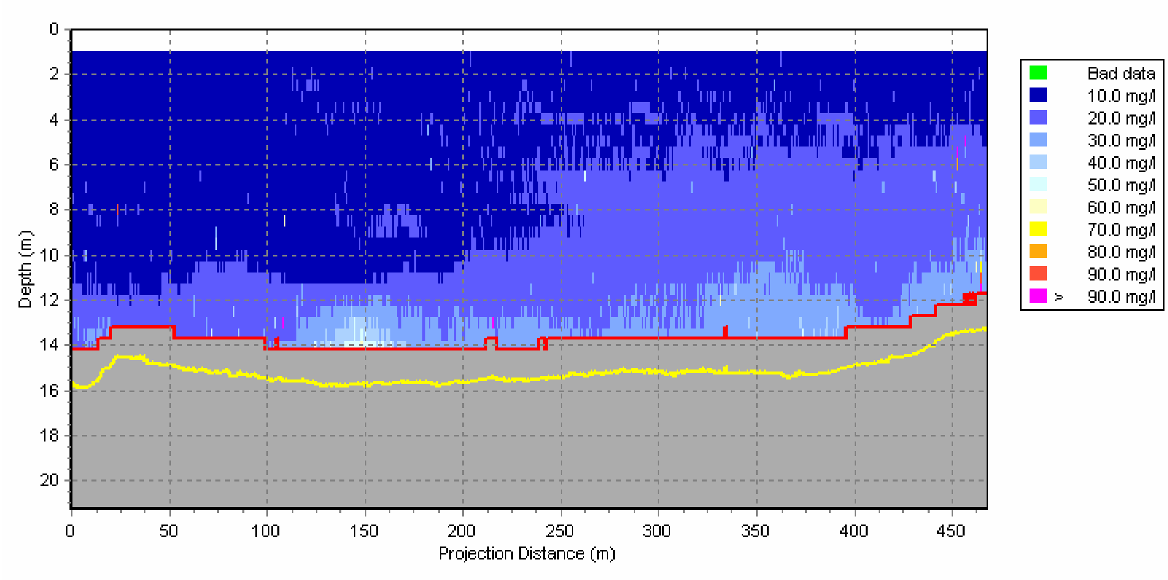

Figure 29. Eighth transect behind the *Melbourne* 58 minutes after first transect.

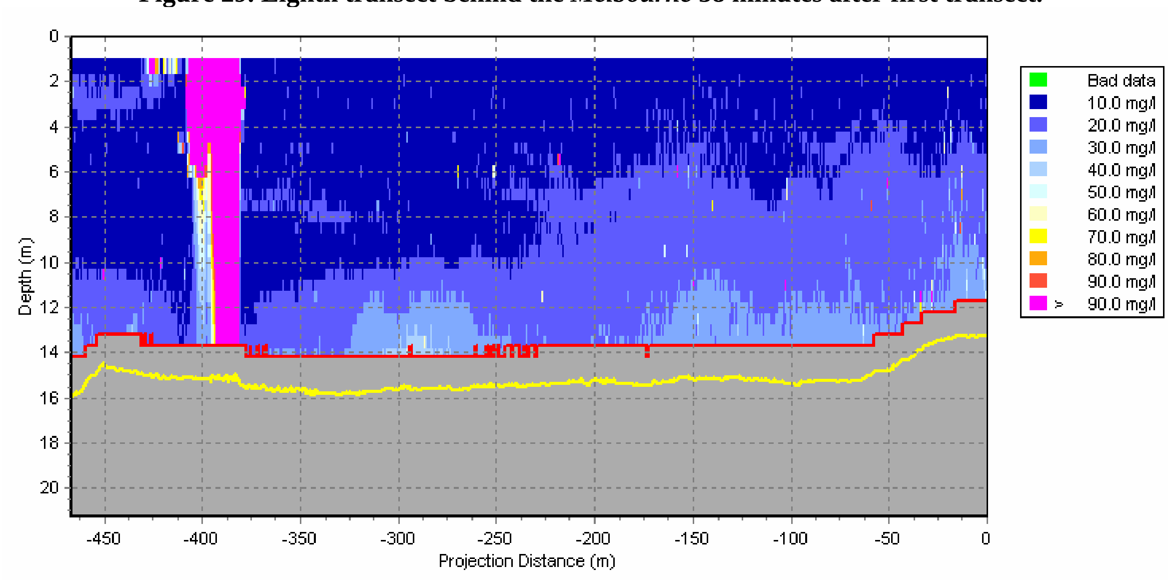

Figure 30. Ninth transect behind the *Melbourne* 1 hour and 5 minutes after first transect.

CONCLUSIONS

Although the present study did not attempt to track the dispersion trajectories of ship traffic-induced suspended sediment plumes, substantial evidence was collected of the relative spatial scales of resuspension as well as the decay rate of plumes at a fixed point in the navigation corridor. The passage of several tugs in tandem with barges, while disturbing the upper portion of the water column, did not appear to measurably affect the bottom. Likewise, passage of an outgoing car carrier did not create a prominent plume. However, acoustic signatures clearly depicted large areas of bottom and water column disturbance for maneuvering container ships, with evidence of significant movement and resettlement of sediment. For a 10-month period from September 2002 to June 2003 an average of 13.2 vessel arrivals and/or departures occurred in Newark Bay on a daily basis, of which 4.9 passages involved vessels with a draft equal to or greater than 35 ft (10.7 m) (based upon data provided by the Port Authority of New York and New Jersey). The frequency of deep draft vessel arrivals and departures on a daily basis suggests that vessel movements probably represent a significant contribution to the net sediment resuspension budget in the Newark Bay system.

Studies are currently underway to determine the far-field fate of sediments mobilized by deep draft vessels as they pass through Newark Bay. Results of the new studies, in tandem with results of the present study, should provide valuable data in support of future environmental assessments of navigation projects. Accurate assessments should be based on knowledge that places dredging, shipping, and natural sources of sediment resuspension into perspective with each other. A regulatory focus on one source while ignoring the others can defeat the ultimate goal of finding solutions for environmental protection while sustaining economically viable port development. Management of dredging projects to minimize resuspension represents just one piece of a complex puzzle. Ultimately the effectiveness of such management practices in terms of either cost or protection of target resources depends upon the timing and magnitude of contributions of each source to the entire sediment resuspension budget.

REFERENCES

Bohlen, W.F. (1980). "A comparison between dredge induced sediment resuspension and that produced by natural storm events." *Proceedings of the 17th Coastal Engineering Conference*, Sydney, Australia, Published by the American Society of Civil Engineers, New York, NY, pp.1700-1707

Clarke, D., Reine, K., Dickerson, C., Zappala, S., Pinzon, R., and Gallo, J. (2007) "Suspended sediment plumes associated with navigation dredging in the Arthur Kill Waterway, New Jersey." *Proceedings of the 18th World Dredging Congress*, WEDA, Lake Buena Vista, FL.

Dellapenna, T.M., Mead, A.A., Gill, G.A., Lehman, R.D., and Warnken, K.W. (2006). "The impact of shrimp trawling and sediment resuspension in mud dominated, shallow estuaries." *Estuarine, Coastal and Shelf Science* In press.

Durrieu de Madron, X., Ferre, B., Le Corre, G., Grenz, C., Conan, P., Pujo-Pay, M., Buscail, R., and Bodiot, O. (2005). "Trawling-induced resuspension and dispersal of muddy sediments and dissolved elements in the Gulf of Lion (NW Mediterranean)." *Continental Shelf Research* 25:2387-2409

Erdmann, J.B., Stefan, H.G., and Brezonik, P.L. (1994). „Analysis of wind- and ship-induced sediment resuspension in Duluth-Superior Harbor." *Water Resources Bulletin* 30(6):1043-1053

Ferre, B., Guizen, K., Durrieu de Madron, X., Palanques, A., Guillen, J., and Gremare, A. (2005). "Fine-grained sediment dynamics during a strong storm event in the inner-shelf of the Gulf of Lion (NW Mediterranean)." *Continental Shelf Research* 25:2410-2427

Fredette, T.J., Bohlen, W.F., and Rhoads, D.C. (1988). "Erosion and resuspension effects of Hurricane Gloria at Long Island Sound dredged material disposal sites." *Proceedings of Water Quality ‚88*, Charleston, SC, Published by the U. S. Army Corps of Engineers Committee on Water Quality, Washington, D. C.

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

Lohrer, A.M., Hewitt, J.E., and Thrush, S.F. (2006). "Assessing far-field effects of terrigenous sediment loading in the coastal marine environment." *Marine Ecology Progress Series* 315:13-18

Pennekamp, J.G.S., Blokland, T., and Vermeer, E.A. (1991). "Turbidity caused by dredging compared to turbidity caused by normal navigation traffic." Central Dredging Association – Permanent International Association of Navigation Congresses Conference, Amsterdam, The Netherlands, 9pp.

Renger, V.E., and Bednarczyk, K. (1986). "Schiffahrtserzeugte schwebstofftransporte im Nessmersieler aussentief." *Die Kueste; Archiv fir Forschung und Technik an der Nord- und Ostsee* 44:89-132

Ruffin, K.K. (1998). "The persistence of anthropogenic turbidity plumes in a shallow water estuary." *Estuarine, Coastal and Shelf Science* 47:579-592

Schoellhamer, D.H. (1996). "Anthropogenic sediment resuspension mechanisms in a shallow microtidal estuary." *Estuarine, Coastal and Shelf Science* 43:533-548

Schoellhamer, D.H. (2002). "Comparison of the basin-scale effect of dredging operations and natural estuarine processes on suspended sediment concentration." *Estuaries* 25(3):488-495

Sosnowski, R. A. (1984). "Sediment resuspension due to dredging and storms: An analogous pair." *Proceedings of the Conference Dredging '84*, Clearwater Beach, FL, Published by the American Society of Civil Engineers, New York, NY, pp.609-618