APPENDIX 4

ASSESSMENT OF SHIP-INDUCED SUSPENDED SEDIMENT PLUMES IN NEWARK BAY, NEW JERSEY

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1 INTRODUCTION

1.1 Purpose

The purpose of this report is to understand and quantify the spatial and temporal extent of sediment resuspension attributable to deep-draft vessel traffic within the navigational channels of Newark Bay.

1.2 Background

Although a great deal of effort has been made historically to characterize and quantify sediment resuspension during dredge operations, 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 (Figure-1). Few attempts have been made to evaluate other natural or anthropogenic sources of resuspension (e.g., Fredette et al. 1988; 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 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). A summary of vessel traffic arriving and departing Newark Bay (Port Elizabeth and Port Newark) from September 1, 2002 to June 30, 2003 was compiled from data provided by the Port Authority of NY/NJ (PANY/NJ 2006). During this period, approximately 400 ships per month, or 13 ships per day, arrive and depart from Newark Bay. Of those ships, approximately 150 per month (about 37%), or 5 per day, are deep “deep draft” vessels with a draft of 35-feet or more. The majority of the ships are container/ro-ro ships (about 80%) with another 12% being car carriers. The container ships draft between 15 and 42.5-feet, whereas the car carriers draft between 22 and 32-feet.

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 total suspended solids (TSS) monitoring associated with dredging activities, opportunities arose to examine sediment resuspension during channel transits of several vessels arriving and departing from the Port of Elizabeth and the Port of Newark; both Ports are located within Newark Bay.

2 METHODS

2.1 Current Regime and Plume Surveys

Plumes were surveyed with an acoustic Doppler current profiler (ADCP) using methods consistent with those described in the companion document (USACE 2006) on monitoring 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 current profile surveys.

2.2 Water Samples

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 channels during mechanical dredging was available and applied to the ADCP data.

2.3 Data Analysis

Conversion of acoustic backscatter data to estimates of TSS concentration was accomplished by application of a robust 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.

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 in the water column 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.

3 RESULTS

3.1 Weather Conditions

Local climatological data for Newark Liberty International Airport was obtained from the National Climatic Data Center operated by the National Oceanic & Atmospheric Administration. The ambient survey of Port Elizabeth Channel was performed on July 6, 2006 between 1230 and 1630. During the survey period, skies were overcast and no ground precipitation was observed, although a total of .25-inches of precipitation was recorded at Newark Airport for the 24-hour day. During the ambient survey, dry bulb temperatures ranged between 75-79° F with winds out of the west between 5-15 mph. The relative humidity ranged between 41% and 52%. Sunrise was at 0432 and sunset was at 1930.

Ship traffic surveys were performed in the afternoons of July 9, 2006 and July 10, 2006. No precipitation was observed during either survey, although a total of 0.04-inches of precipitation was recorded at Newark Airport on July 9 and no precipitation was recorded on July 10. Dry bulb temperatures ranged between 84-85° F with winds out of the east between 5-15 mph. The relative humidity ranged between 40% and 51%. On both days, sunrise was at 0434 and sunset was at 1929.

3.2 Ambient Plume Survey

Ambient data was collected during a flood tide ADCP current profile survey of Port Elizabeth (Figure 2). During this survey, 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.

3.3 Ship Traffic Survey 9 July 2006

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. During the rotation maneuver a prominent surface plume of increased turbidity was generated (Figures 3 and 4). A repetitive ADCP transect of approximately 500 meters in length was established across the area in which the ship had turned (Figure 5), extending west 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 (9) survey lines were completed between 1309 and 1404 hrs (Figures 6 thru 18). A time series of events and associated TSS concentrations are found in Table 1 below.

Table 1: Time series of 9 July 2006 Ship Traffic Survey

Transect No.	Time	TSS	Plume description	Figure No.
1	1309	Air contamination prevented TSS estimation	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.	6
2	1315	>90mg/l lower half of the water column	Most of the entrained air had dissipated upward in the water column and is seen as a distinct surface feature. A clear acoustic signature of bottom resuspension is present.	7
3	1323	70 – 90 mg/l near bottom	A general settling and spreading of the plume had occurred.	8
4	1333	90mg/l near bottom	TSS pattern similar to the previous transect.	9
5	1338	70 mg/l near bottom	Further settling of the plume.	10
SEE NOTE 1				
6	1342	70-80 mg/l near bottom	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* was still easily detected with elevated concentrations near the bottom.	14
7	1349	50-60mg/l near bottom	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.	15
8	1354	<60 mg/l near bottom	Plume remained near the bottom.	16
SEE NOTE 2				
9	1359	<50 mg/l near the bottom	The re-suspension plume from the *YM North* was still visible.	18

Note 1: At approximately 1330 hrs the car carrier ARC *Freedom* exited Port Newark and crossed the repetitive transect at approximately 1342 hrs (Figures 11 and 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.

Note 2: Just prior to the start of the ninth and final transect of this repetitive line survey the tug *Iona McAlister* (Figure 19), which had been assisting in docking operations of the *YM North*, departed Port Elizabeth and crossed the repetitive transect line.

3.4 Ship Traffic Survey 10 July 2006

Prior to the start of the survey the container ship *Hudson* (Figure 19) entered Port Elizabeth. 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. The *Melbourne* turned directly into the Port Elizabeth Channel and proceeded to the dock. The *Melbourne* did create a prominent surface turbidity plume (Figure 22). A time series of events and associated TSS concentrations are found in Table 2 below.

Table 2: Time series of 10 July 2006 Ship Traffic Survey

Transect No.	Time	TSS (mg/l)	Plume description	Figure No.
1	1358	>90 mg/l along the entire water column	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.	23
2	1402	>90 mg/l along the entire water column	Significant disturbance of the bottom while the residual plume from the *Hudson* remained intact (on the right).	24
3	1407	90 mg/l near bottom	The two (2) separate plumes from the *Hudson* and the *Melbourne* began to merge into a single diffuse plume at this point.	25
4	1410	70 mg/l near bottom	The two (2) plumes were now completely merged into a single plume.	26
5	1416	50 mg/l or less near bottom	Continued dissipation of the overall plume.	27
6	1421	40 mg/l or less near the bottom with isolated areas of 50 mg/l.	Further decay and settlement of the plume.	28

Transect No.	Time	TSS (mg/l)	Plume description	Figure No.
7	1424	40 mg/l or less near bottom with isolated areas of 50 mg/l.	Further decay and settlement of the plume.	29
SEE NOTE 1				
8	1456	<40 mg/l near bottom.	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.	30
9	1503	**SEE NOTE 2**		31

Note 1: 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.

Note 2: 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 one hour following ship passage.

3.5 Correlation of Water TSS Samples and Acoustic Estimates of TSS Concentration

Although a dedicated set of water samples were not collected for this study, a total of 89 samples were collected and analyzed during the dredge monitoring study in Elizabeth Channel. Laboratory TSS concentrations in these samples ranged from 5.6 to 300 mg/l, producing an excellent calibration set, although the overall number of samples at the upper end of the concentration gradient was limited. In Figure 32, the entire population of gravimetric measurements and acoustic estimates 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. When plotted with respect to paired samples, i.e. gravimetric and acoustic measures collected synoptically, some variation is seen for a few individual pairs (Figure

33), but the absolute differences in TSS concentration are small. This variation is primarily due to the logistical constraint of obtaining synoptic measurements in a very small volume of water while concentration gradients change on very short time and distance scales. 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 operating bucket to consistently obtain such samples.

4 CONCLUSIONS

During the course of TSS monitoring associated with dredging activities, opportunities arose to examine the suspended sediment plumes of several vessels arriving and departing from the Port of Elizabeth and the Port of Newark within Newark Bay. Data were collected using an acoustic Doppler current profiler on 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 from maneuvering container ships, with evidence of significant movement and resettlement of sediment. The frequency of deep draft vessel arrivals and departures in the Newark Bay complex on a daily basis suggests that vessel movements represent an ongoing contribution to the net sediment resuspension budget.

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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 (left side). An operating dredge is also visible at the entrance to the Elizabeth Channel. (Image courtesy of CHM2Hill).

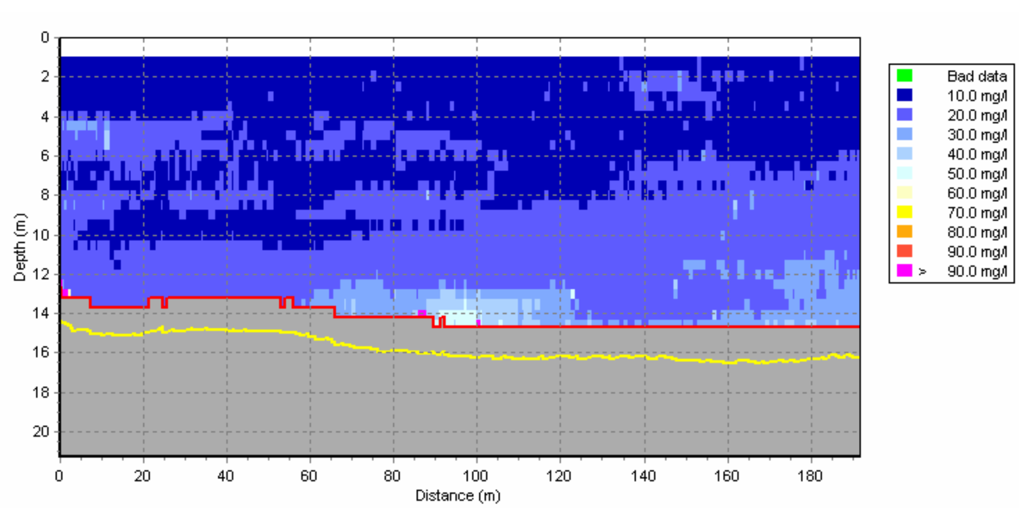

Figure 2. Ambient TSS concentrations across a transect on 6 July 2006 during a middle phase of a flooding tide. This transect location coincides with that of ensuing ship passage surveys.

Figure 3. Surface turbidity created by maneuvering the container ship *YM North*.

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

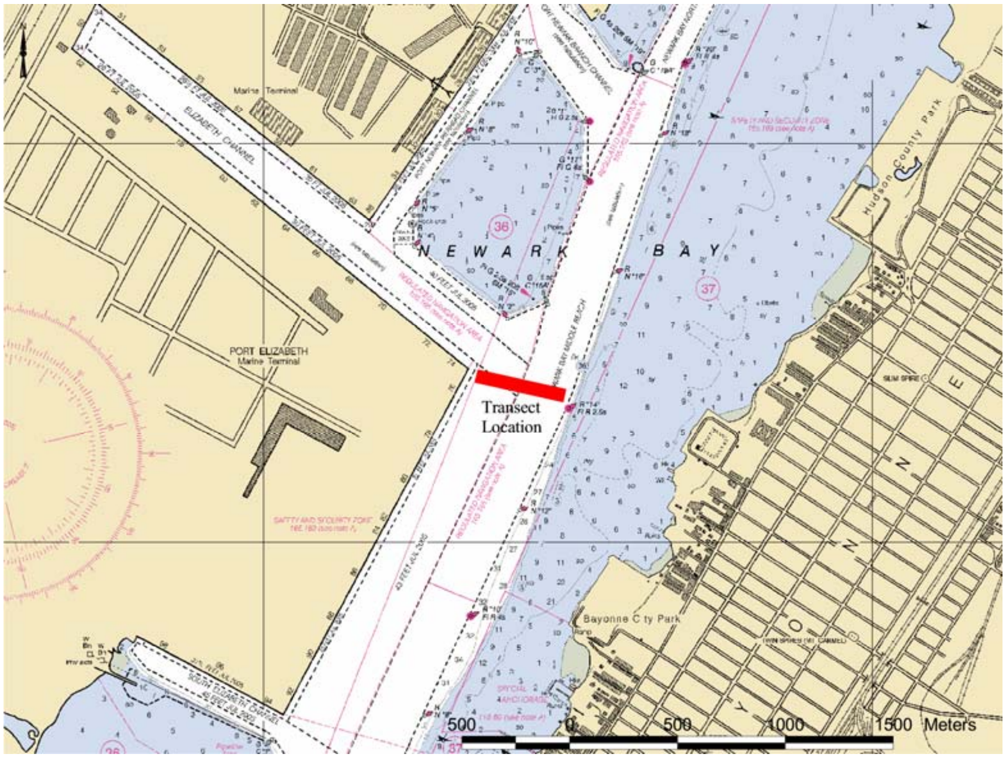

Figure 5. Repetitive transect location.

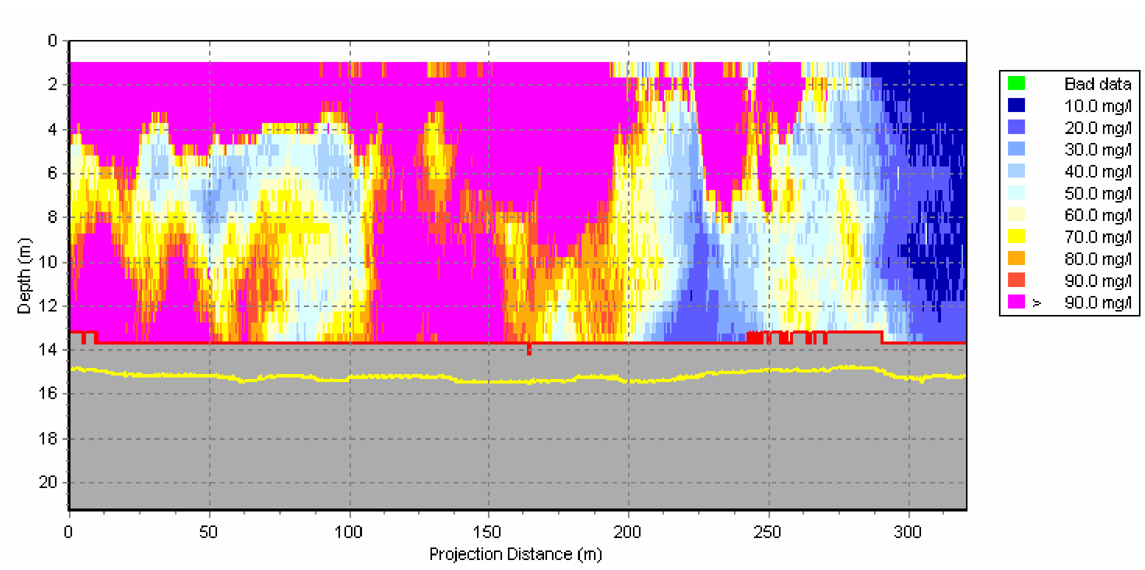

Figure 6. First transect directly behind *YM North* (Time 0).

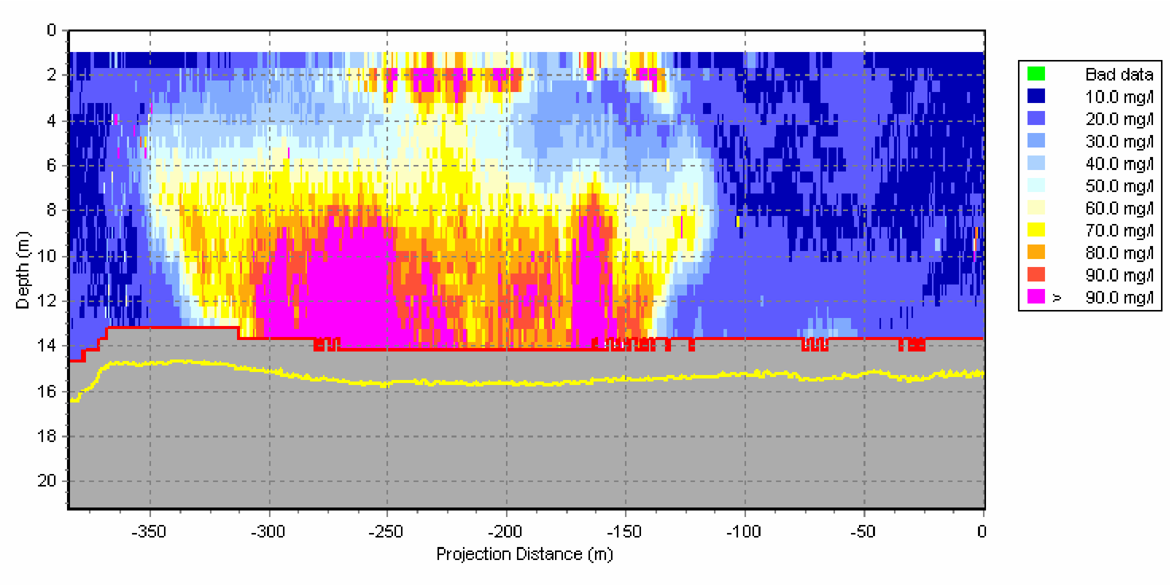

Figure 7. Second transect behind *YM North* 6 minutes after first transect.

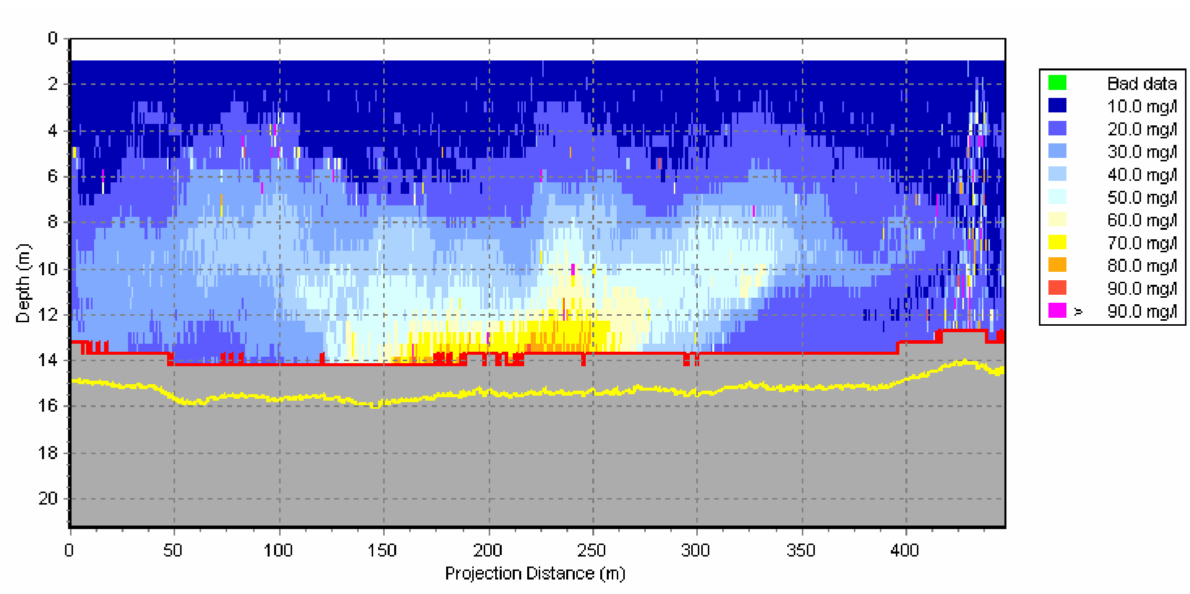

Figure 8. Third transect behind *YM North* 19 minutes after first transect.

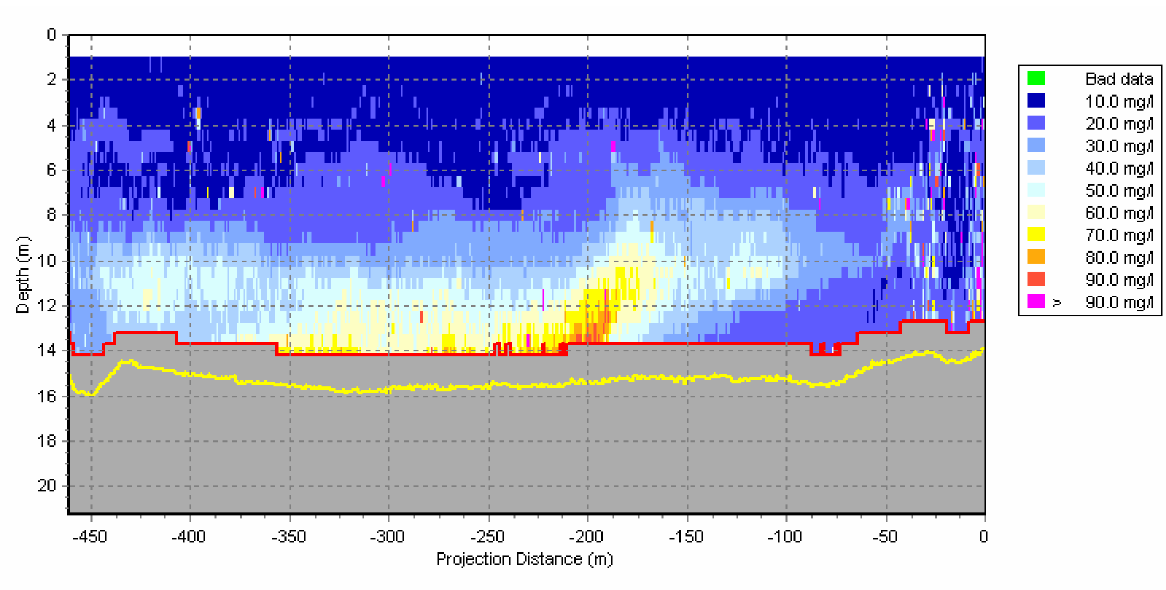

Figure 9. Fourth transect behind *YM North* 24 minutes after first transect.

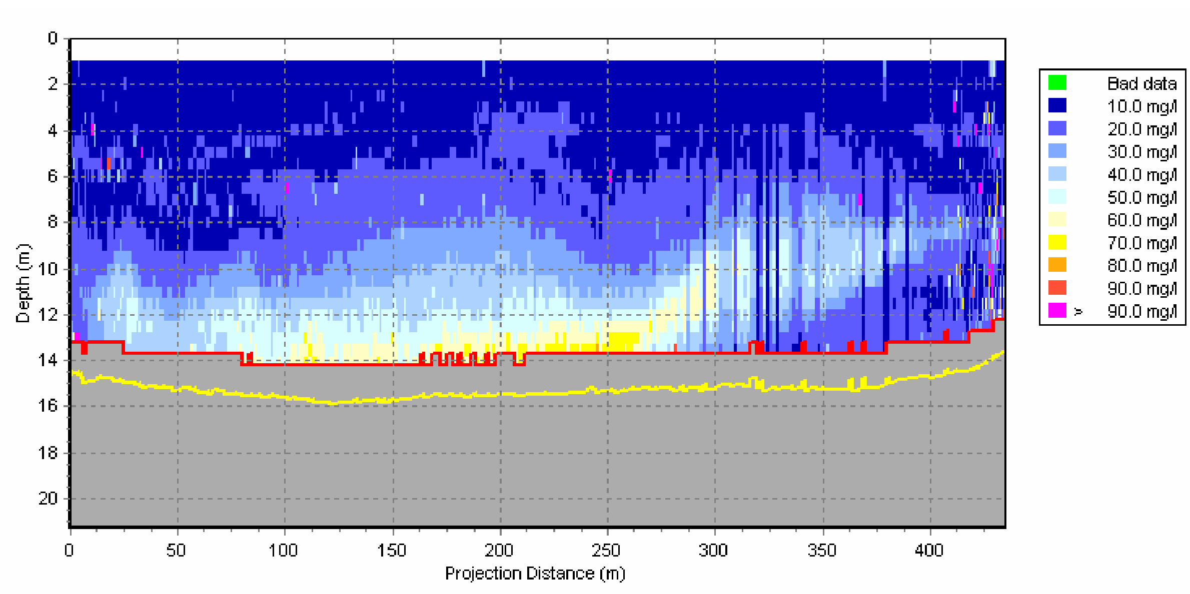

Figure 10: Fifth transect behind *YM North* 29 minutes after first transect.

Figure 11. Car carrier ARC *Freedom* approaching repetitive transect location.

Figure 12. Car carrier ARC *Freedom* crossing repetitive transect.

Figure 13. Tug and loaded scow crossing repetitive transect.

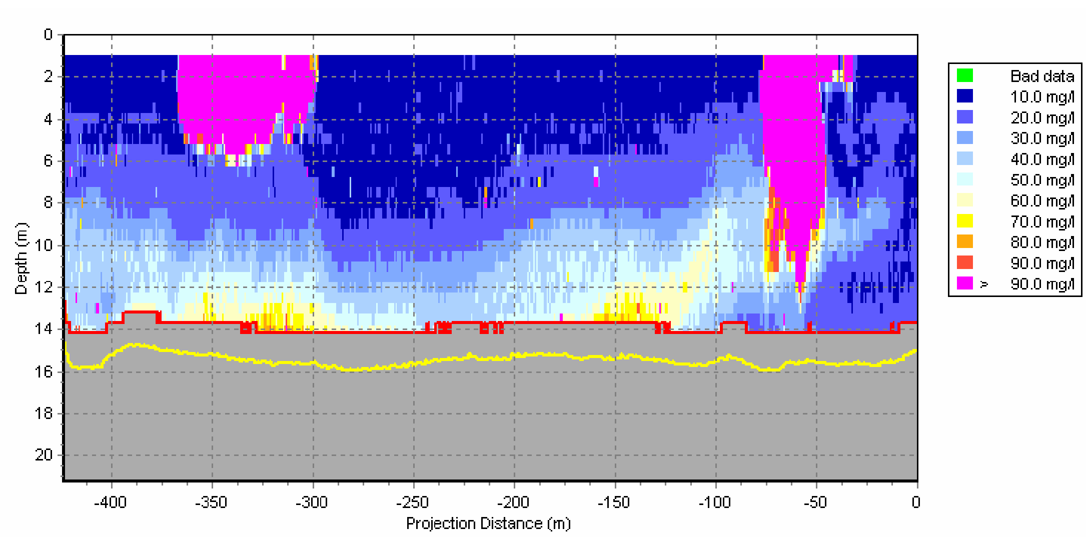

Figure 14. Sixth transect behind *YM North* 33 minutes after first transect showing ship wake signatures of a tug and barge (left) and the car carrier ARC *Freedom* (right).

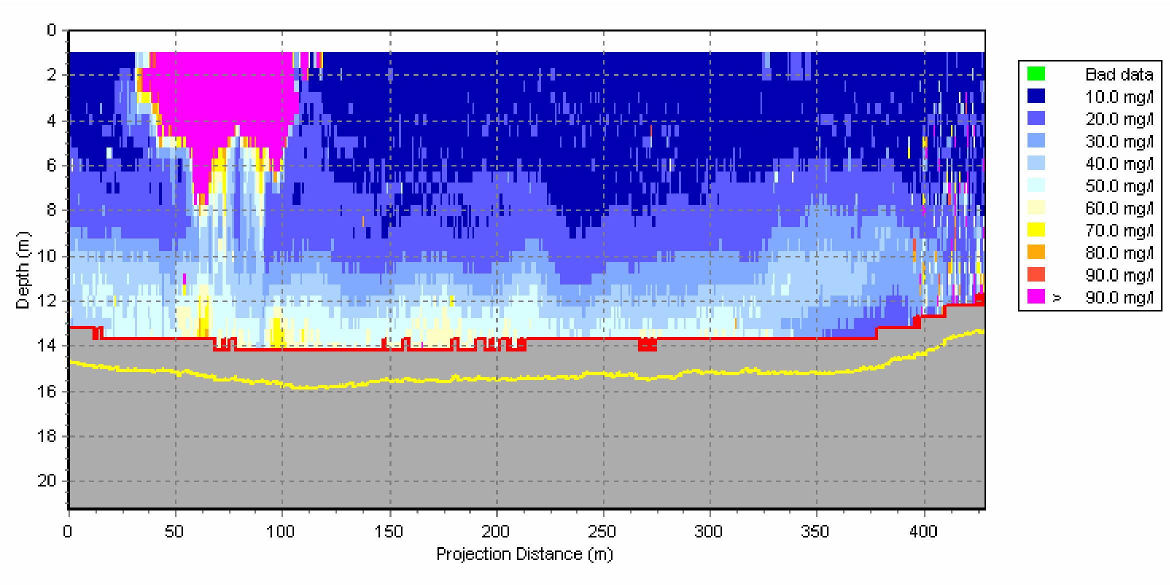

Figure 15. Seventh transect behind *YM North* 40 minutes after first transect with the wake signature of the tug and scow still visible on the left while the wake signature from the car carrier ARC *Freedom* has dissipated.

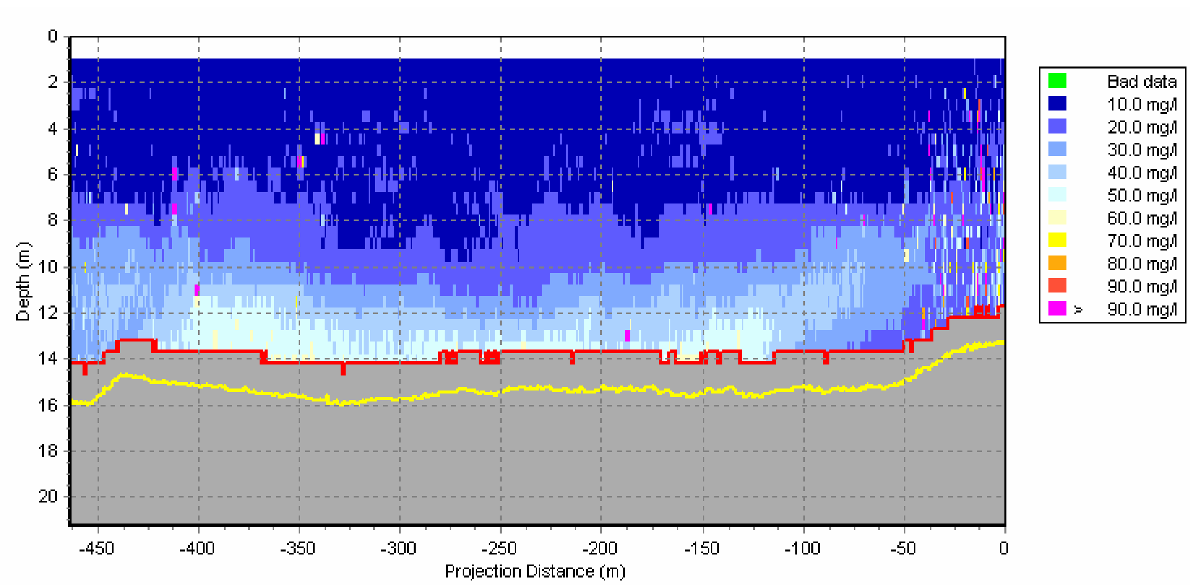

Figure 16. Eighth transect behind *YM North* 45 minutes after first transect, both wake signatures now dissipated.

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

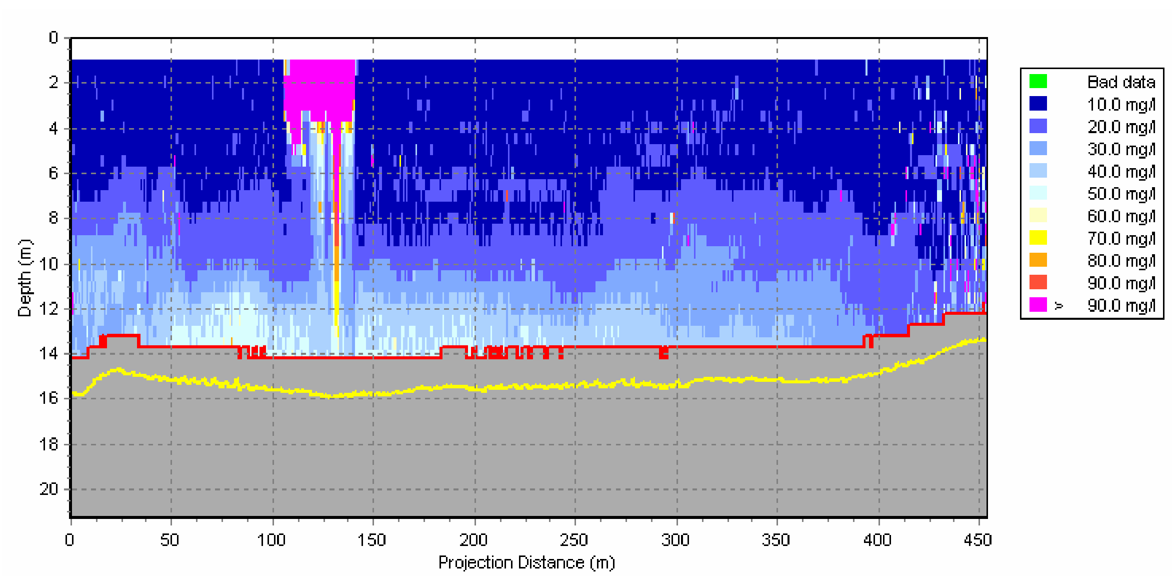

Figure 18. Ninth transect behind *YM North* 50 minutes after first transect showing wake signature of entrained air from tug boat *Iona McAlister*.

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

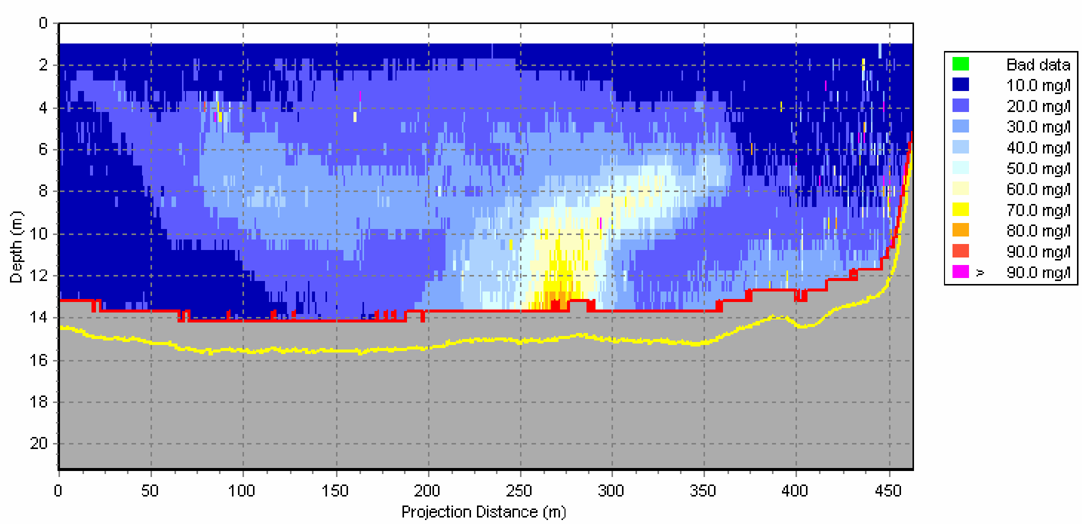

Figure 20. Residual plume from container ship CMA CGM *Hudson*.

Figure 21. Container ship CSCL *Melbourne* inbound Newark Bay Channel.

Figure 22. Surface turbidity created by the container ship CSCL *Melbourne*.

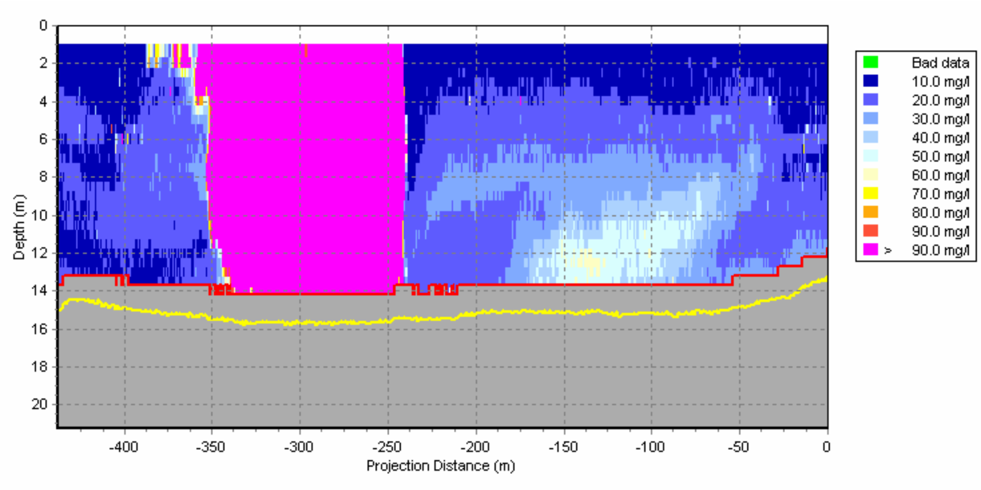

Figure 23. First transect directly behind the *Melbourne* (Time 0). The wake signature of the *Melbourne* is clearly visible on the left extending from the water surface to the bottom. The residual plume from the *Hudson* is still visible on the right.

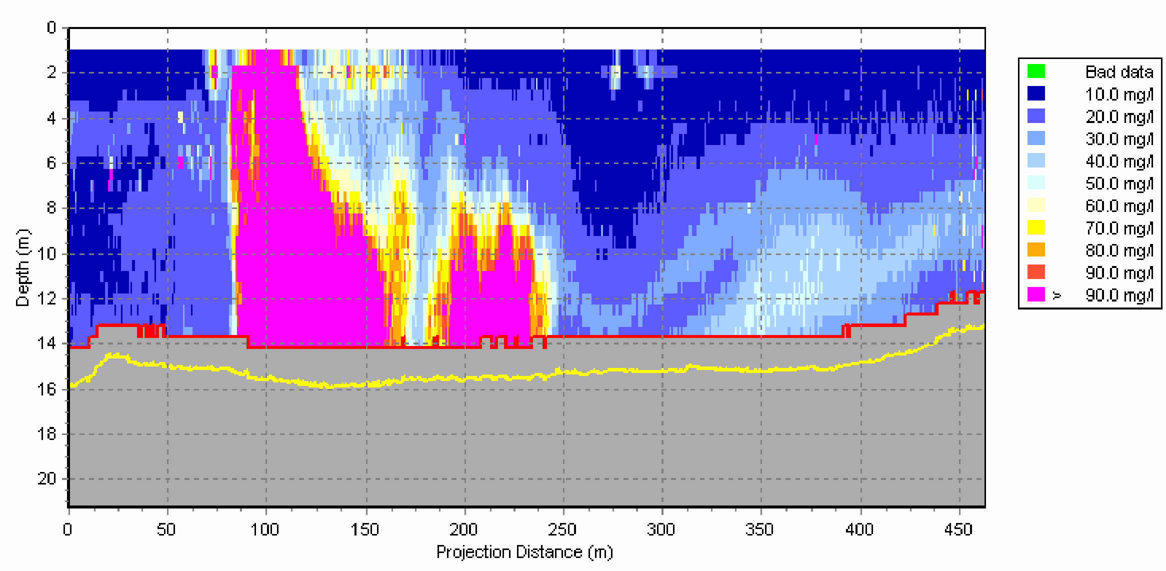

Figure 24. Second transect behind *Melbourne* 4 minutes after first transect.

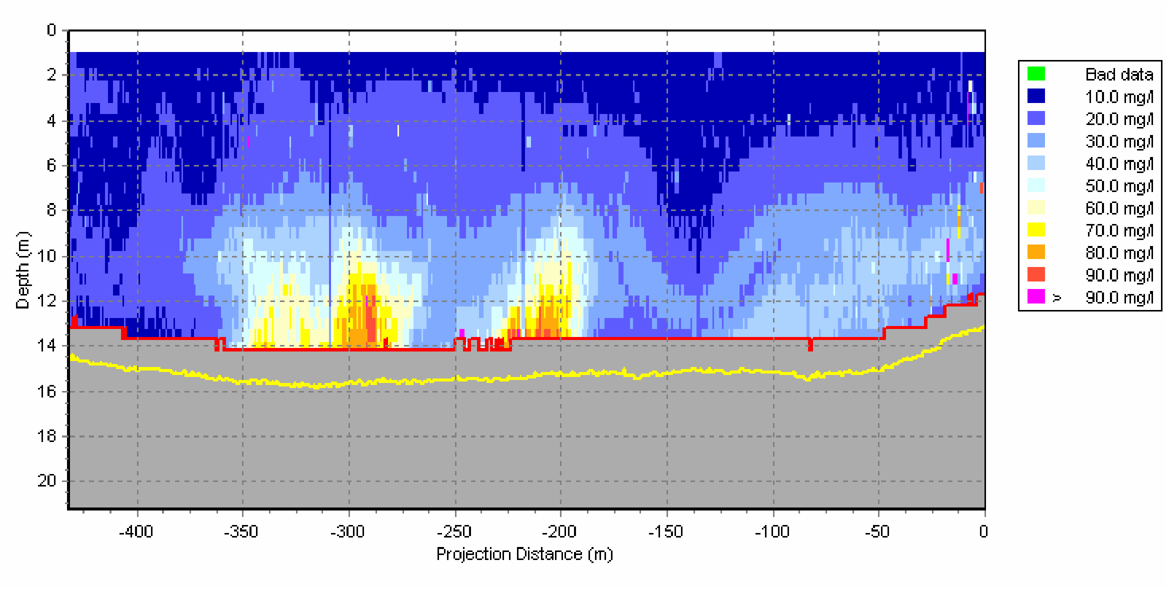

Figure 25. Third transect behind *Melbourne* 9 minutes after first transect.

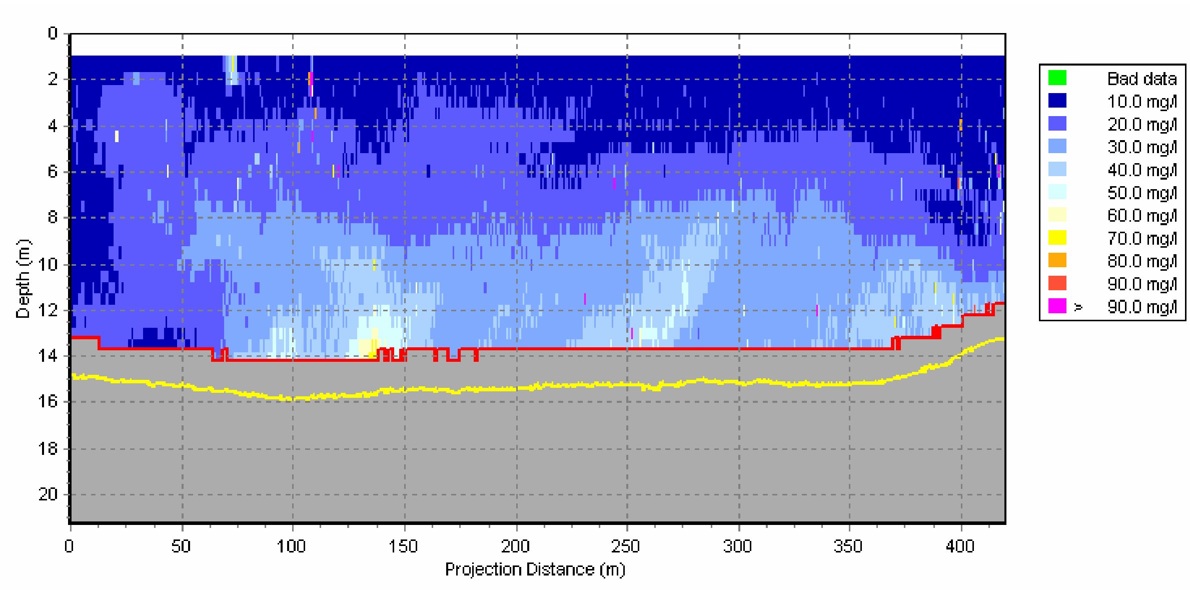

Figure 26. Fourth transect behind *Melbourne* 13 minutes after first transect.

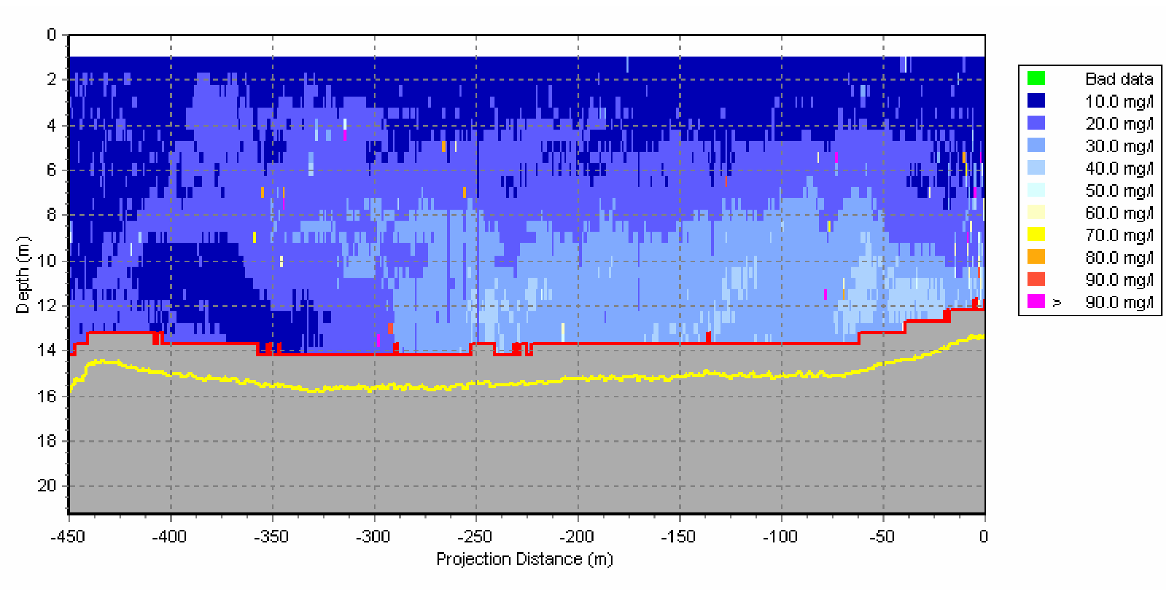

Figure 27. Fifth transect behind *Melbourne* 18 minutes after first transect.

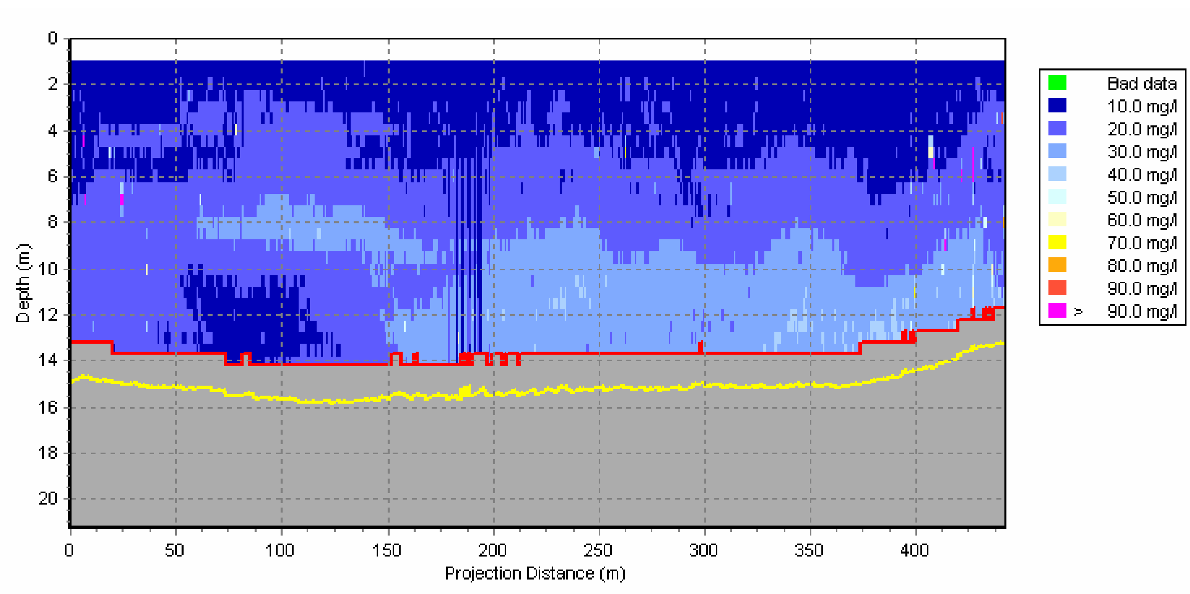

Figure 28. Sixth transect behind *Melbourne* 23 minutes after first transect.

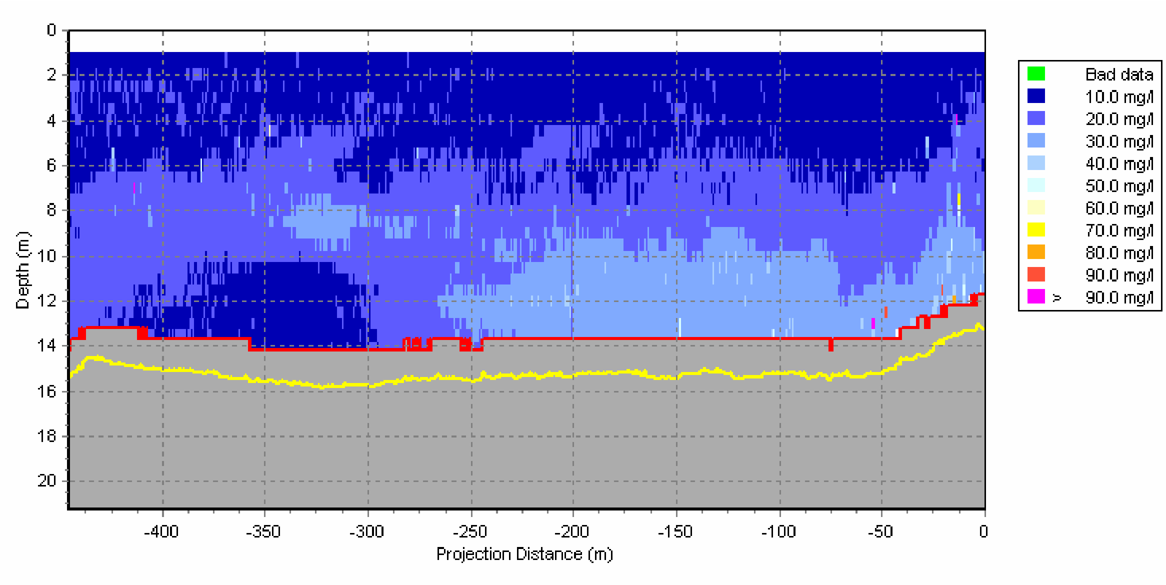

Figure 29. Seventh transect behind *Melbourne* 26 minutes after first transect.

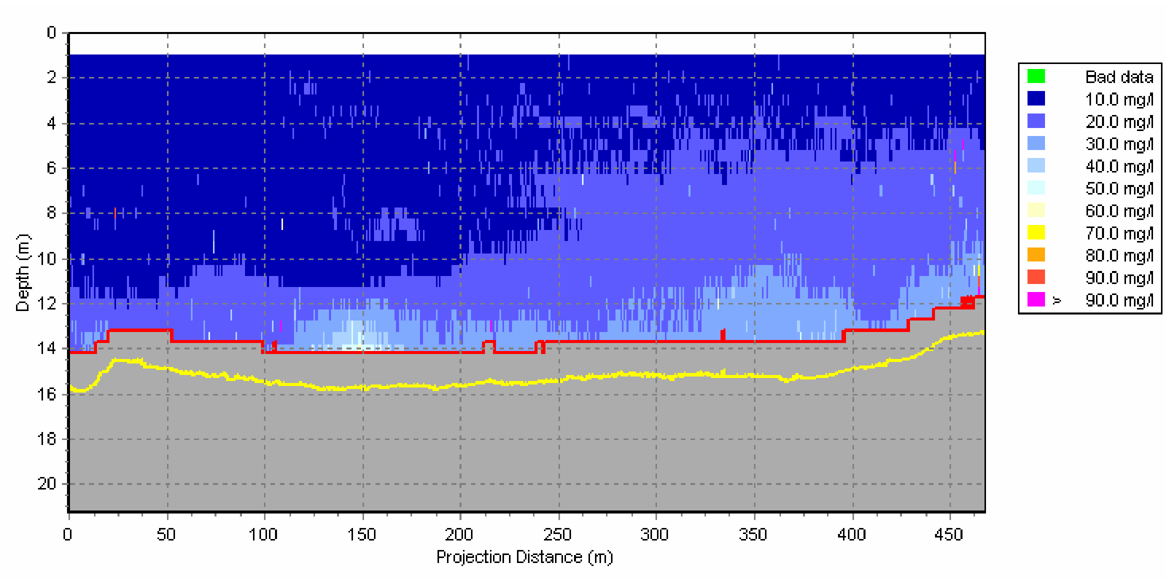

Figure 30. Eighth transect behind *Melbourne* 58 minutes after first transect.

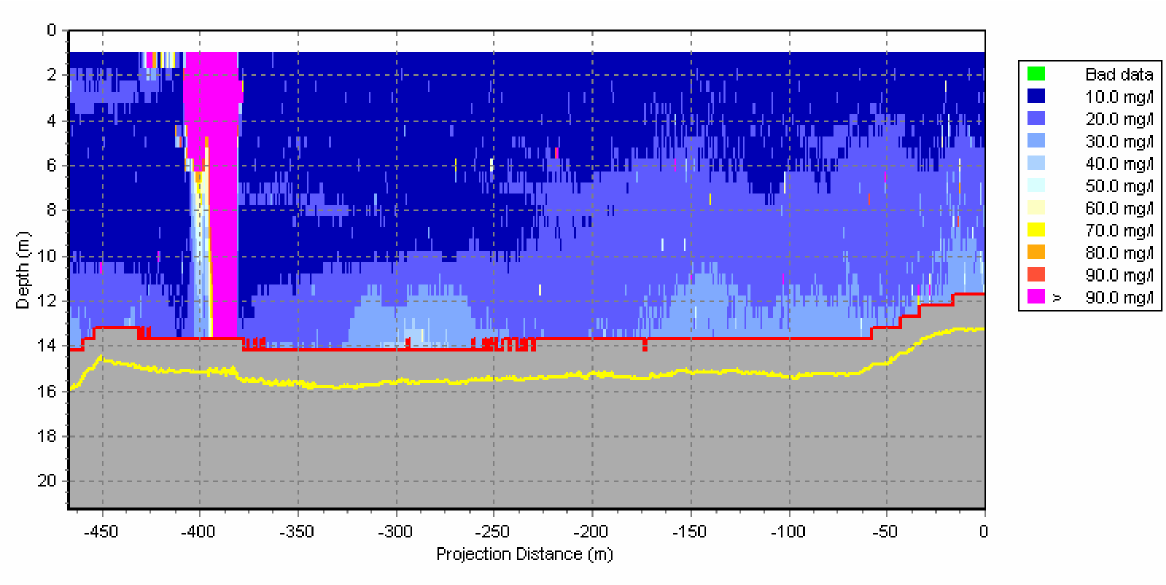

Figure 31. Ninth transect behind *Melbourne* 1 hour and 5 minutes after first transect.

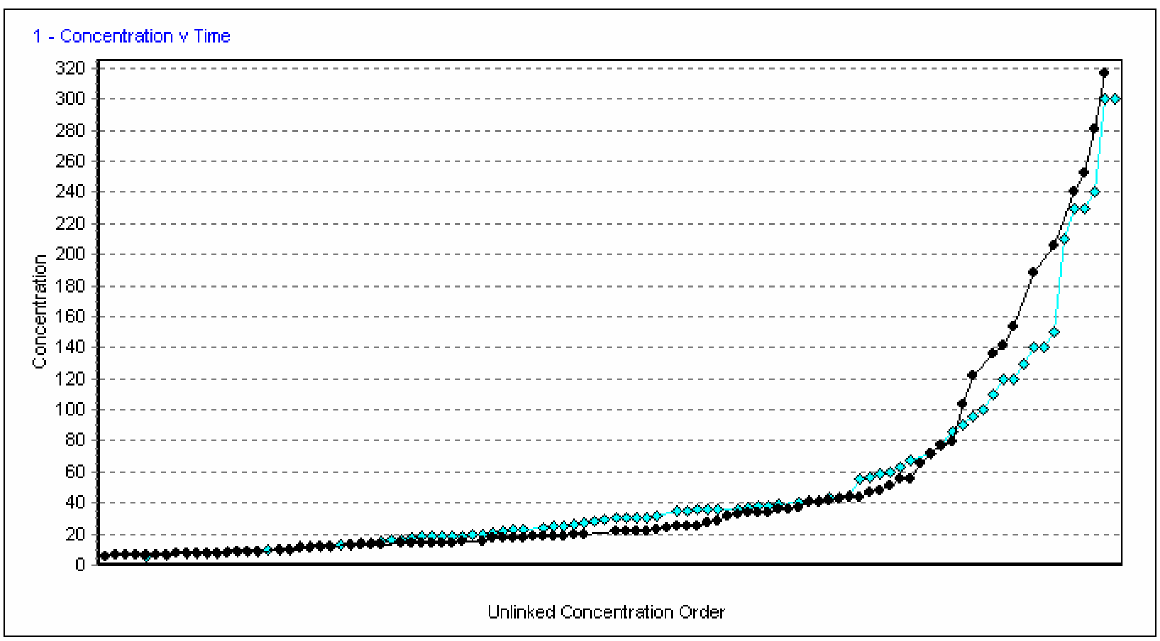

Figure 32. Comparison of gravimetric and acoustic estimates of TSS concentration for the entire population of 89 water samples in rank order. Gravimetric results are represented in blue, and acoustic estimates in black.

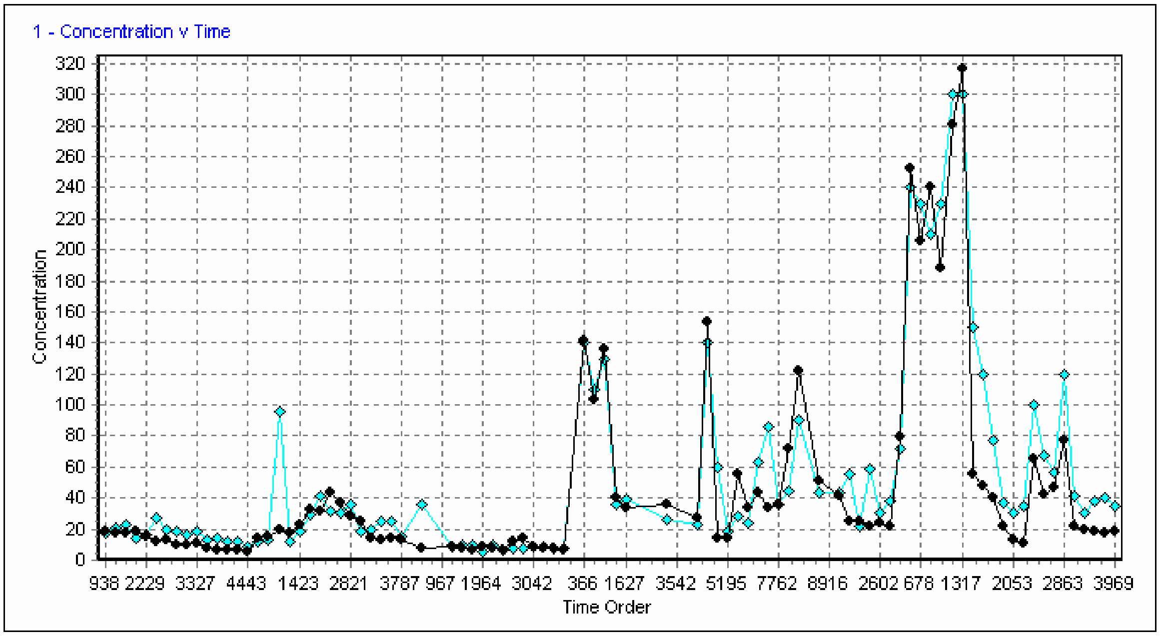

Figure 33. Comparison of gravimetric and acoustic estimates of TSS concentration for paired synoptic samples presented in the order of sample collection. Gravimetric results are represented in blue, and acoustic estimates in black.