Post-Disposal Monitoring of the Auckland Marine Disposal Ground

for Coastal Resources Ltd.

Permit no. 555

February 2011

Bryna Flaim and Dr. Willem de Lange

Coastal Marine Group

Department of Earth and Ocean Science

University of Waikato

Hamilton, New Zealand

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

In December 2009, Maritime New Zealand (MNZ) granted a permit for disposal of 5000 m^3 of muddy dredged material from Pine Harbour Marina at the proposed Auckland Marine Disposal Ground located approximately 25 km east of Great Barrier Island. The site, identified in 2007, had been the focus of a preliminary environmental impact assessment based on review of previous studies in similar areas as well as baseline field data collection. The findings showed that the site was potentially suitable for long-term disposal of dredged material. The granted permit set out the impact hypothesis for the proposed disposal. The monitoring methodology set out in the Permit was developed to assess this impact hypothesis. The disposal was undertaken during March and April 2010 and the required monitoring was undertaken. This report is a summary of the findings of these monitoring studies undertaken before, during and after the disposal operations. This document also fulfils the requirement of the Permit that after the trial monitoring, a review of monitoring techniques would be undertaken. Changes resulting from this, and agreed upon by MNZ, would then be incorporated into the Management Plan for the final consent as previously agreed.

OBJECTIVES

The main objectives of the monitoring and this summary report are:

- *1.0* Confirm that the site is not ecologically significant.
- *2.0* Determine the fate of dredged material disposed at the site.
- *3.0* Assess the dispersion potential of a dredged material plume arising from the disposal process.
- *4.0* Evaluate the methodologies used.
- *5.0* Make recommendations for future monitoring. This objective is wider than the impact hypothesis with Objectives 1.0, 2.0 and 3.0 covering those matters listed in the impact hypothesis.

SUMMARY OF FINDINGS

Objective 1.0: Physical and Ecological State

Site Morphology – A multibeam echosounder (MBES) survey, undertaken at the site prior to disposal of dredged material, showed that the seafloor is very flat with no significant bathymetric features. The seafloor slopes gently from SW to NE (depth contours run approximately parallel with the coastline) with water depth ranging from approximately 135-155 m across the 5km X 5km area surveyed. The post-disposal MBES survey in the same area showed no noticeable bathymetric change at the disposal release location or in any other corresponding areas. This was not unexpected as the total quantity of material released was small (~4800 m^3) compared to the significant water depth (140 m) water. Additionally, each of the 9 loads landed in slightly different locations, so there was no build-up of disposed material to form a mound.

Sediment type – Sediment cores retrieved across the site prior to disposal consistently contained a very soft greenish/golden-brown mud that was fluffy and loose in the top several centimeters becoming somewhat stiffer with depth. The cores were approximately 12 cm in length which indicated a potentially stiffer layer of sediment below that the gravity corer used was unable to penetrate. Visual observations of post-disposal cores were much the same as pre-disposal cores with the exception of cores from the centre of the site (the disposal release coordinates) and from 250 m east of the centre. Cores from these two locations showed a distinct black layer of fine sediment at the sediment/water interface which was thicker at the centre location compared to the layer seen in the cores from 250 m east of the centre. Lasersizer particle size analysis showed no significant change in particle size distribution between pre- and post-disposal core samples. Particles size composition in the samples collected across the site was mostly in the range of clay to fine sand. The average percentage of particles less that 0.063 mm (clay and silt sized particles) was 57±7% and 54±7% in pre- and post-disposal samples, respectively.

Sediment Chemistry – 6 samples retrieved following disposal were analyzed by Hill Laboratories for heavy metals (Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, and Zinc) as well as total petroleum hydrocarbons (TPH). In all six samples, the concentrations of all heavy metals tested were below the Effects Range Low level (ER-L). Elutriation of these samples did not show any significant desorption which would indicate bioavailability and all metals in all samples were at least at the 95% trigger value for species protection meaning that according to the ANZECC guidelines, the concentration of a heavy metal available for uptake by organisms would not affect 95% of the species. In some cases, the 99% trigger level of species protection was achieved. There are no guidelines recommended for TPH levels, but all samples tested contained lower levels than samples taken directly from Pine Harbour Marina, the origin of the disposed material. Additionally, there was no significant difference in TPH levels between the centre site sample and the others as might be expected due to the higher concentration of disposed material at the centre of the site.

Biology – The benthic infaunal biota identified at the sites during the June 2009 and January 2010 pre-disposal surveys as well as the June 2010 post-disposal survey seem to be typical of communities of the deeper shelf regions of the northeast coast. Some of the variation in composition and abundance between the pre- and post-disposal surveys may be attributable to disposal of dredged material, but seasonal and local variation may also have contributed. Only one epibenthic organism (Pennatualcea/Sea Pen) was identified in the underwater video footage and no pelagic organisms were observed. The site does not appear to be a habitat for commercially significant species such as crayfish and fin fish and there is no indication that is ecological significant.

Objective 2.0: Dredged Material Fate

Post-disposal MBES bathymetric data did not show the formation of a mound in the vicinity of the disposal release coordinates therefore a volume-deposited estimate was not possible. However, MBES backscatter data, reflecting the intensity of the returned signal and thus the density of the seafloor substrate, show multiple patches of higher density material around the disposal release coordinates (within ~250 m). These patches most likely represent the deposition 'footprint' of the component of the material that descended rapidly through the water column immediately after release of each load of material. Although the material dredged from Pine Harbour was a very soft mud, similar to the natural site sediment, the dredging method (backhoe) allows some of the *in situ* consolidated sediment structure to remain intact after placement in the hopper which upon release descends rapidly to the seafloor as dense clods or blocks of material. It is likely the patches of higher intensity backscatter are a signature of these dense clods. Even though it is not possible to distinguish 9 distinct patches, these signatures were not recorded anywhere else in the post-disposal survey area, so it is probable that all 9 nine loads of disposed material were in fact deposited within 250 m of the release coordinates. Most likely several loads may appear as one large patch where two or more loads may have deposited very near to or overlapping each other. The distinctive black material observed in the post-disposal sediment cores collected at the centre of the site as well as 250 m east of centre verify that the disposed material did in fact deposit at or near the centre of the site. Additionally, as part of plume monitoring surveys undertaken during disposal of 4 of the loads of dredged material at the site, Acoustic Doppler Current Profiler (ADCP) backscatter data clearly showed very high concentration suspended material, likely the dense clods, descending as a large mass through the water column within minutes after disposal on each occasion. The highest near-bed concentrations were never recorded further than a couple hundred meters from the disposal release coordinates.

Objective 3.0: Plume Dispersion

On 4 out of the 9 loads disposed, monitoring surveys were undertaken immediately following release of dredged material over the designated coordinates. Wind and sea conditions varied on each of the 4 surveys. Several means for monitoring the suspended sediments levels at the site were employed, but the most comprehensive data came from ADCP backscatter (mentioned above) which, similar to MBES backscatter, indicates a higher density medium, in this case the water column. As such, a higher ADCP backscatter return indicates a higher suspended sediment concentration, thus allowing for plume tracking. The greatest dispersion on each occasion occurred in the surface waters, but the highest concentrations after the first several minutes were observed in the near-bed waters. Near the surface, the greatest dispersion after 1 hour was approximately 750 m beyond the disposal release coordinates observed during wind and sea conditions equal to Beaufort Scale 4. On all 4 occasions, after 1 hour, suspended sediment levels throughout the water column decreased to an undetectable level through dispersion, dilution, and settling processes. On no occasion was the plume detected beyond the boundary of the disposal site, and in most cases it was not detected at significant concentrations further than 500 m from the centre of the site.

CONCLUSION

i. The disposed material descended as an aggregated mass to the sea floor. The volume entrained in the water column could not be quantified but was very low as predicted.

ii. The entrained material dispersed as a plume in the ambient current and was not detectable beyond the site boundary.
iii. The deposited material remained stable on the sea floor during the monitoring period.
iv. No fish or crayfish were identified at the disposal site.
v. Copper, Lead, and Zinc concentrations were somewhat higher at the centre of the site, but at all other sampling locations within the site, heavy metal concentrations were not significantly different from levels detected at the control site. All levels measured were below the ER-L level.
vi. Benthic infaunal composition appears to be typical of the area. After disposal of ~4800 m^3 of dredged material, there was no discernable change in the composition and abundance of benthic biota.
vii. Overall, the trial disposal did not result in any impacts outside the site and had a minimal impact within the disposal site. No environmental issues arose which were not predicted or gave rise to concerns that future disposal may result in any significant adverse impacts.

ONGOING MONITORING STUDIES

4.0 Methodological Assessment

In order to achieve the first three objectives of the site investigations, many different methodologies were utilized. This provided an opportunity to assess which methods/equipment were most appropriate and were required for future monitoring. In the case of the plume monitoring surveys, several methodologies were used for the same purpose as detailed surveys in such conditions are rare and the most efficient method under the circumstances is generally 'situation-specific'. The table below summarises the methods utilized to achieve objectives 1.0, 2.0, and 3.0

Method	Capabilities	Application applied	Viable method
MBES	Defines bathymetry; backscatter can be indicative of substrate type	Determined water depth, morphological features (none), and density variations of the seafloor substrate	Yes
Gravity corer	Samples the top 12cm of seafloor sediment; maintains *in situ* layering	Visual observations of intact cores; samples retrieved were analysed for sediment type, chemistry, and benthic organisms	Yes; only for visual obs., sed. type, and chem.
Lasersizer analysis	Particle size analysis; possible tracer	Particle size distribution for baseline info. and comparison to post-disposal	Yes; only if disposed material has significantly different size distribution that natural sediment.
Heavy metal and TPH analysis	Determines heavy metal and TPH concentration of the	Used to assess the ecological health of the site following disposal	Yes; can also be potentially used as a tracer of deposited

	sediment		material.
Benthic organism analysis	Determines type and quantity of species present	Used to determine baseline info on species present at the site; post-disposal identification used to assess for	Yes; but samples should be collected using a device which covers more surface area (e.g. box dredge) and samples
Nimrod (dynamic penetrometer)	Provides info on geotechnical properties of the substrate	Used for determining dredged material fate	No
ADCP	Provides 3D current speed/direction as well as indication of suspended sediment concentrations (SSC)	Used for tracking the plume of suspended sediment following disposal of material	Yes; suggest a slightly amended methodology
BIOFISH	Provides 3D data on water column properties (to a limit) such as turbidity, salinity, and density	Used for tracking the plume of suspended sediment following disposal of dredged material	No; impractical for the deep water site.
Optical turbidity sensors	Provide turbidity data and correlation of ADCP backscatter data	Used for tracking the plume of suspended sediment following disposal of dredged material	Anchored turbidity stations were impractical because the plume is too transient. One robust sensor attached to the main survey vessel to
Water samplers	Provide actual SSC data and correlation for other turbidity measurements	Used to correlate BIOFISH, turbidity sensor, and ADCP data	No, impractical for the spatial expanse that needs to be included and because of the transient nature of the plume.

RECOMMENDATIONS FOR FUTURE MONITORING

The monitoring undertaken confirmed the impact hypothesis that the disposed material will descend as an aggregated mass and will remain stable on the seafloor under normal conditions. As an outcome of this, impacts beyond the disposal site are not expected to occur. Future monitoring should therefore focus on the general physical, chemical and biological state of the disposal site and should also serve to confirm that the disposed material is not migrating beyond the site boundary.

Plume monitoring – In the cases surveyed, wind and sea conditions equating to a Beaufort Scale 4 resulted in a maximum dispersion of 750 m away from the disposal release coordinates. The designated site area has a radius of 1500 m, twice the observed maximum dispersion distance. Based on the previous observations it is possible to assume that under worse wind and sea conditions, a disposal plume will have a greater dispersion distance. Under wind and sea conditions equating to a Beaufort Scale 5 or 6, it is not likely that the plume will be dispersed beyond the boundary of the site based on the results of the monitoring undertaken. Therefore, it is recommended that so long as dredged material is disposed during wind and sea conditions less than or equal to a Beaufort Scale 6, that no further plume monitoring is necessary. Typically, it is not safe to dispose material under conditions stronger than that if the method for disposal is by towed split hull hopper.

Disposal site monitoring – After disposal of 50,000 m^3 of dredged sediment at the site the following assessments should be undertaken:

i. MBES survey of the site (MBES data should be recorded in the same area as previous surveys)
   - bathymetry change and backscatter variation should be examined and compared to previous datasets
   - if a disposal mound is detected, a volumetric estimate should be derived for comparison to future estimates

ii. Collection of 6 cores including 1 control core (samples should be collected from the same positions as previously collected samples)
   - make visual observations of the core looking at color, layering, and other distinctive physical characteristics
   - undertake heavy metal and TPH analysis to assess chemical characteristics of the site and if possible trace disposed material by comparing concentrations to those comprising the chemical signature of the material disposed there
   - compare all data to previous post-disposal core data and look for evidence of the presence of dredge material

iii. Collection of 6 box dredge samples (or similar) including one from a control location (samples should be collected from the same positions as previously collected samples)
   - Sieve and preserve samples immediately after retrieval
   - Sort, identify, and count benthic organisms in each sample
   - Assess diversity, abundance, and compositional change and compare to data from previously collected samples

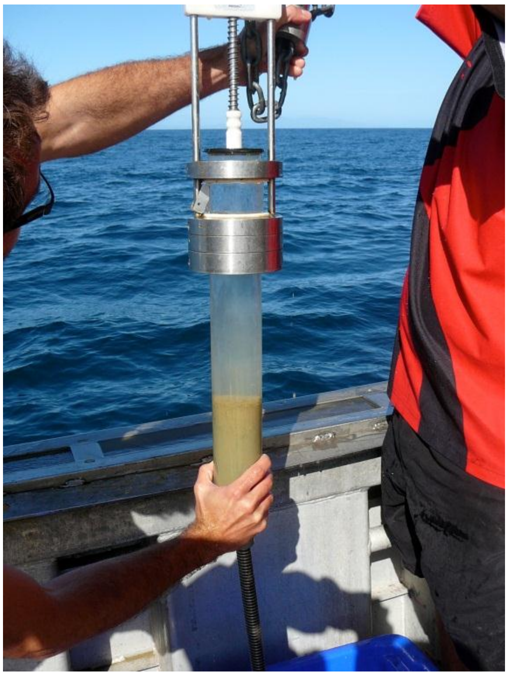
If no evidence of loss of material or migration of the disposed material beyond the boundaries of the site is detected, then disposal operations can resume. The monitoring should be repeated after disposal of 150,000 m^3 and 300,000 m^3 of dredged material. If evidence of loss of material or migration of the disposed material beyond the boundaries of the site is detected, then disposal operations should be suspended pending further assessment.

AUCKLAND MARINE DISPOSAL GROUND

MONITORING SERIES

REPORT 1 BENTHIC CORES: INITIAL OBSERVATIONS

February 2011



1.1 BACKGROUND

In December 2009, consent was granted by Maritime New Zealand (MNZ) for disposal of 5000 m^3 of muddy dredged material from Pine Harbour Marina at the Auckland Marine Disposal Ground 25 km east of Great Barrier Island (Figure 1.1). Conditions for post-disposal monitoring in Coastal permit no. 555, include '*Grid sampling of bottom sediments using a 'SHIPEK' grab sampler or similar*' (Maritime New Zealand, 2009, p.4). Accordingly, this report describes visual observations of benthic sediment samples retrieved prior to the trial disposal undertaken in April 2010 and compares them to samples retrieved in June 2010 following disposal of ~4800 m^3 of dredged material. Detailed data resulting from these sediments samples, such as sediment chemistry and texture as well as benthic faunal composition are reported in following reports.

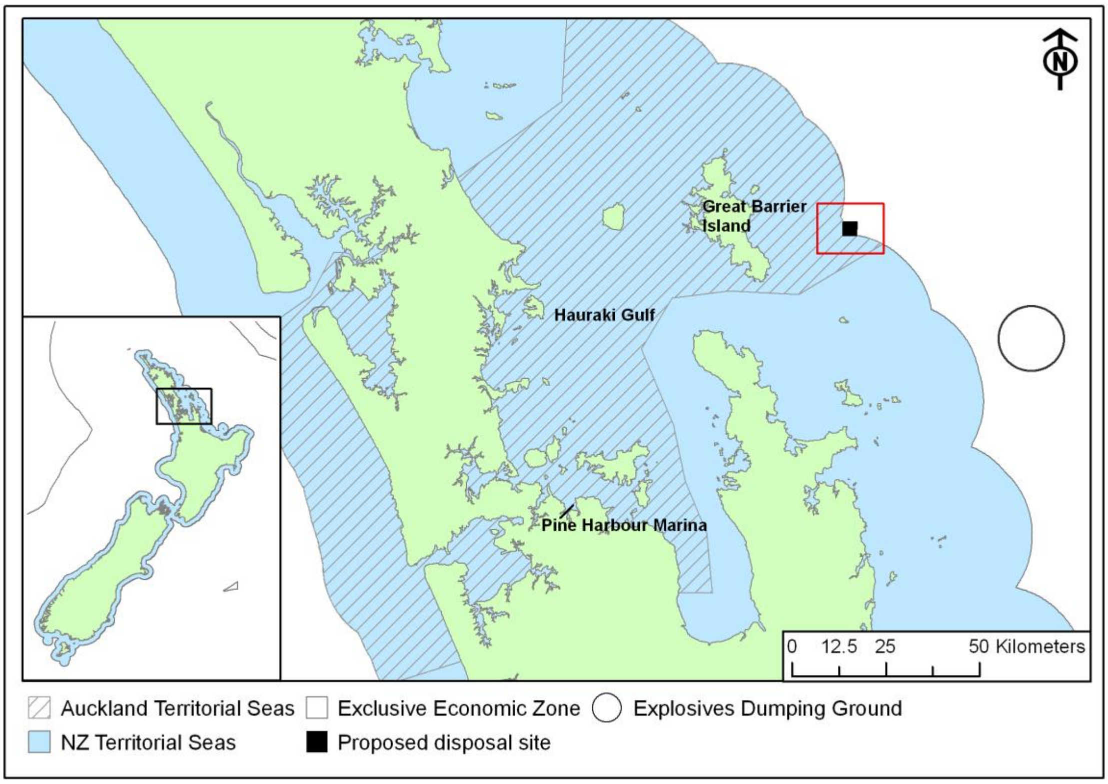


Figure 1.1 New Zealand territorial seas (TS)[1] and surrounding Exclusive Economic Zone (EEZ)[1] of the Auckland Coastal Marine Area (CMA). Red square denotes map location of Figure 1.2.

The proposed Auckland Marine Disposal Ground was first surveyed in November 2007, the findings of which were reported in Flaim and Healy (2008). Methods relating to the retrieval of sediment samples during this initial survey were undertaken using a 'SHIPEK' grab sampler. This method, while reliable for sample retrieval,

[1] Sourced from Land Information New Zealand data. Crown Copyright Reserved. DATA IS NOT COMPLIANT WITH AND CANNOT BE USED IN LIEU OF DATA REQUIRED UNDER SECTION 31.1 OF THE TERRITORIAL SEA [CONTIGUOUS ZONE] AND EXCLUSIVE ECONOMIC ZONE ACT 1977. NOT TO BE USED FOR NAVIGATION.

does not allow for the observation of sediment as it is *in situ* because the sample is highly disturbed in the collection process. For that reason, during the second survey in September 2008, a weighted gravity corer was used to retrieve samples in addition to a 'SHIPEK' grab so that sub-bottom stratification could be better visualised. The gravity coring method proved successful for such purposes and was henceforth used on all subsequent site surveys.

As a requirement of the test disposal consent, the disposal site area was shifted from its original location so that the centre coordinates were a further 1000 m north and 1500 m east from the boundary of the Auckland CMA. As a result of this shift, many sample locations visited during the September 2008 pre-disposal survey were no longer within the site boundaries and a large portion of the new site area had yet to be sampled. Therefore, additional pre-disposal surveys were undertaken in June 2009 and January 2010.

1.2 METHODOLOGY

The centre of the site (H2) is located at 175° 48' 1.382"E, 36° 12' 21.441"S. The sample grid is 500 m X 500 m (Figure 1.2). Eighteen locations were sampled at a 500 m spacing near the centre of the site with increasing spacing with distance from centre. Thirteen locations were sampled within and on the site boundaries and 5 locations were sampled within the monitoring zone surrounding the site boundary. Additionally, 6 control sites (denoted by and 'X') were sampled inside the Auckland CMA boundary. Control samples were introduced into the monitoring program following consultations with MNZ and Auckland Regional Council (ARC). These were chosen randomly during a separate trip to the site in June 2009. Two cores were collected at each location; one care was used for sediment analysis (see Report 4) and the other was used for benthic biota identification (see Report 5). All locations included in Figure 1.2 were sampled pre- and post-disposals, however only samples H1, G2, E2, and E5 from the September 2008 survey correspond with locations sampled in the subsequent surveys.

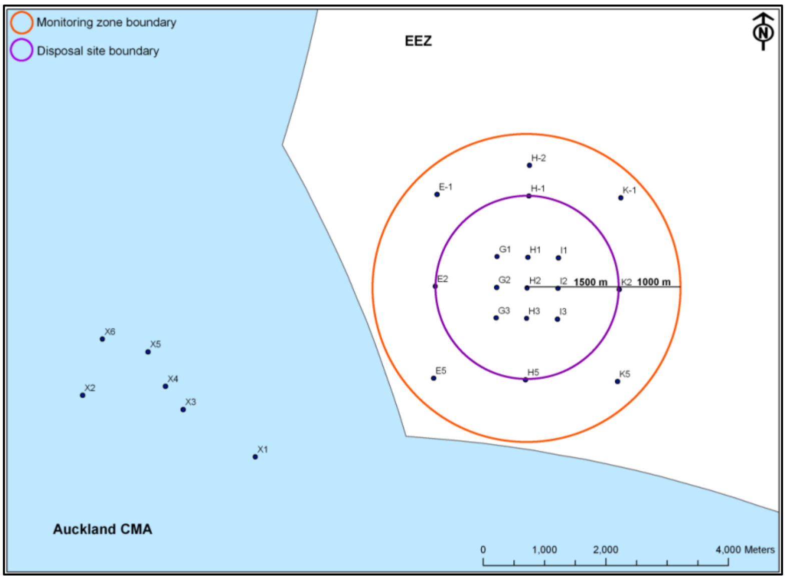


Figure 1.2 Locations of sediment sample retrieval visited during the pre- and post-disposal surveys in June 2009/January 2010 and June 2010, respectively. Locations H1, G2, E2, and E5 were also sampled during the pre-disposal survey of September 2008.

For each deployment, the gravity corer was set with a 70 mm internal diameter Perspex barrel and released in a free-fall to the sea floor. Weight at the top of the device triggers a rubber seal to close on the top of the barrel after contact and penetration into the seabed which then generates a vacuum strong enough to preserve the sample inside the barrel during retrieval. A slack line indicated that the device had come in contact with the seabed and using a motorised winch, the device was then brought back to the surface. As it reached the surface, a plug was inserted into the bottom of the core to contain the sample in the barrel as the seal was typically compromised upon contact with air. After bringing the whole apparatus on deck, the barrel was removed from the device and photographed followed by extrusion into a bag for storage and later analysis (see cover images).

1.3 OBSERVATIONS

Typical sediment cores retrieved from the disposal site prior to the test disposal were approximately 12 cm in length and consisted of two basic layers of muddy benthic sediment. The upper layer, from the seafloor surface to a depth of ~5cm tended to be a light fluffy mud golden brown in colour. In this layer, evidence of small benthic infauna, such as worms on the order of 1 cm in length, was common. At the sea-to-sediment interface the sediment was typically flat showing no evidence of bedforms. The lower layer (~7 cm), from ~5 cm below the seafloor surface to ~12 cm below, consisted of a more consolidated olive green mud (Figure 1.3). These features were common throughout all surveys and at all locations prior to the test disposal.

Following the trial disposal in April 2010, sediment cores retrieved from the majority of sample locations displayed the same features observed in pre-disposal cores with 2 exceptions. At location H2 (Figure 1.2), corresponding to the coordinates where each load of dredged material was released, two sediment cores retrieved consisted of a significant amount of black anoxic mud (Figure 1.4) consistent with the mud dredged from Pine Harbour Marina and disposed at the site (Figure 1.5). The two distinct layers typical of the natural site sediment were not apparent. Instead, in the upper half of the core, black mud was in high concentration and evidently well-mixed with the brown/olive green natural site sediment, with the black mud concentration decreasing with depth within the core. Near the top of the core ‘clumps’ typical of disposed material dredged with a back-hoe digger, as in this case, were evident. Also notable was the thin golden brown layer on the very top of these cores which is likely a result of oxidation of the exposed disposed material. This process would readily occur in anoxic mud after a short period of time. In this case, 1 month had passed after disposal operations ceased before the post-disposal cores were retrieved. Depending on the amount of mixing and bioturbation by benthic infauna, a major portion of the disposed material would be expected to turn this golden brown colour within a short time.

Disposed material was also observed at a previously un-sampled site 250 m east of the disposal coordinates (H2). As previously mentioned, the original sampling grid was 500 m but during the June 2010 survey, upon finding the disposed material at H2, but not at any of the sampling locations 500 m away, it was determined that it would be useful to obtain cores from locations 250 m away to best determine the footprint of the disposed material. As the tug towing the hopper travelled from west to east, releasing at H2 without stopping, it was determined that extra cores 250 m west and east would provide the most useful information.

The cores retrieved from the location 250 m east of H2 (referred to as H2-I2) consisted of the same black mud observed in cores from H2 (Figure 1.6). However, the quantity was significantly less than that at H2. The clumps prevalent in the H2 cores were not apparent at H2-I2. Accordingly, a larger percent of the black mud in the H2-I2 core had become oxidised because the majority of the material was close to the surface of the core.

The cores retrieved from a site 250 m west of H2 (referred to as H2-G2) did not contain any apparent black disposal mud (Figure 1.7). In this case, the core appears very similar to the pre-disposal cores from nearby locations.

Pre-disposal control cores collected some 4 km inside the boundary of the Auckland CMA demonstrate the same features as cores retrieved inside the site boundary (see Appendix I). No apparent changes to the sediment were evident from visual observations of control cores retrieved following test disposal.

1.4 CONCLUSIONS

Pre-disposal site cores, as well as pre-disposal control cores indicate that the shelf in this area is uniformly overlain with a brown to olive green mud that is loose and fluffy at the surface and somewhat more consolidated to a depth of +/- 12 cm. Biological activity is evident at most sample locations to a depth of approximately 5 – 7 cm, but no samples showed evidence of macrofaunal type invertebrates.

Post-disposal cores in a general sense appeared much the same as those collected prior to disposal operations. The exceptions were at H2, the location of hopper release, and at a site 250 m east of that location. Location H2 appeared to have the most significant quantity of the disposed material while a much smaller amount seems to have reached the site 250 m east. No black mud was observed in samples collected at the site 250 m west of H2.

Based on these observations the following conclusions can be made:

i. No disposed material was detected in areas 500 m to the north, south, east, or west of the disposal site coordinates;
ii. No disposed material was detected in areas 250 m to the west of the disposal site coordinates;
iii. A small amount of disposed material was deposited 250 m to the east of the disposal site coordinates; and
iv. The majority of the disposed material descended directly to the seafloor at the point of release from the hopper.

Among other conclusions, further pre- and post-disposal data collected via alternate methods, such as with MBES and under-water video, as stipulated in the consent conditions, will provide more detail as to the spatial extent of the deposited material. Data from those methodologies are reported in proceeding reports.

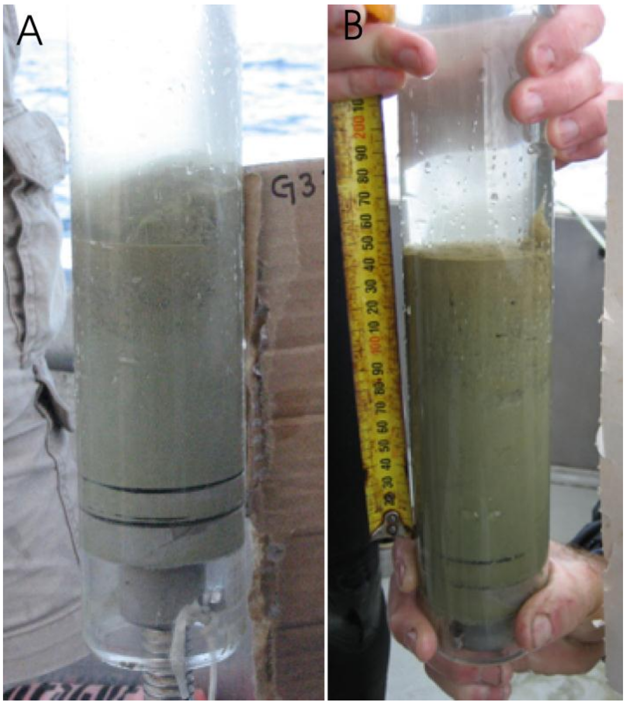


Figure 1.3 Photos of sediment cores retrieved (A) prior to disposal and (B) following disposal. These samples were collected from location G3, but are typical of the majority of samples collected at the disposal site both before and after disposal.

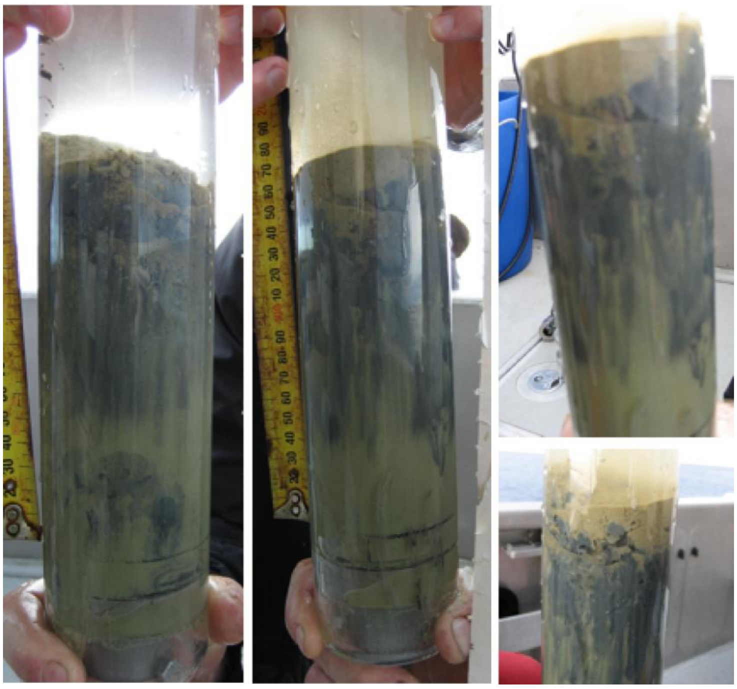


Figure 1.4 Photos of 2 sediment cores with a significant amount of black disposal mud retrieved from location H2 (actual disposal location) June 2010 following the trial disposal in (includes close-up views).

Figure 1.5 Black anoxic mud being dredged from a Pine Harbour Marina berth (end of March 2010) (photo: Bryna Flaim).

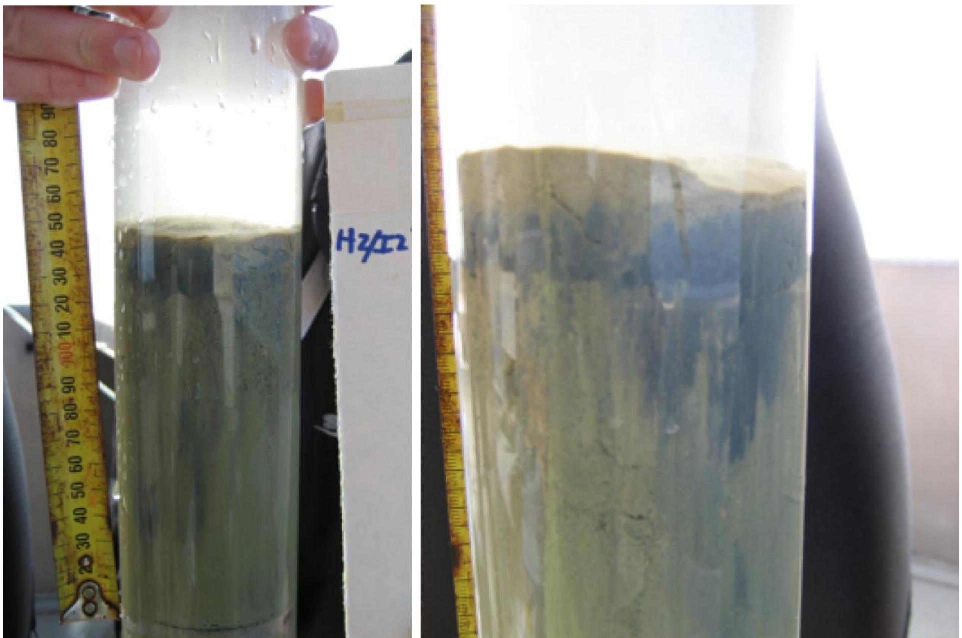


Figure 1.6 Photo of sediment core with a small amount of black disposal mud retrieved from location H2-I2 (250 m east of the actual disposal location) June 2010 following the trial disposal in (includes close-up view).

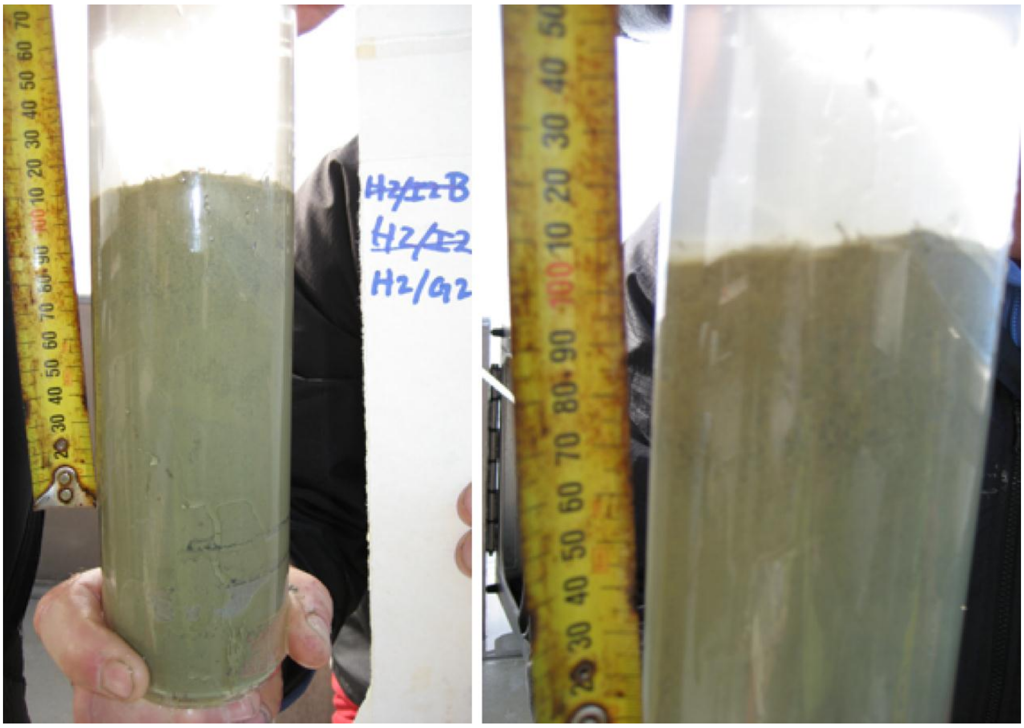


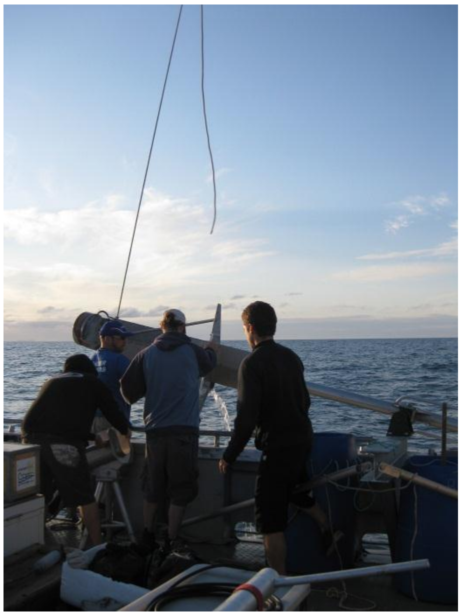
Figure 1.7 Photo of sediment core with no black disposal mud retrieved from location H2-G2 (250 m west of the actual disposal location) June 2010 following the trial disposal in (includes close-up view).

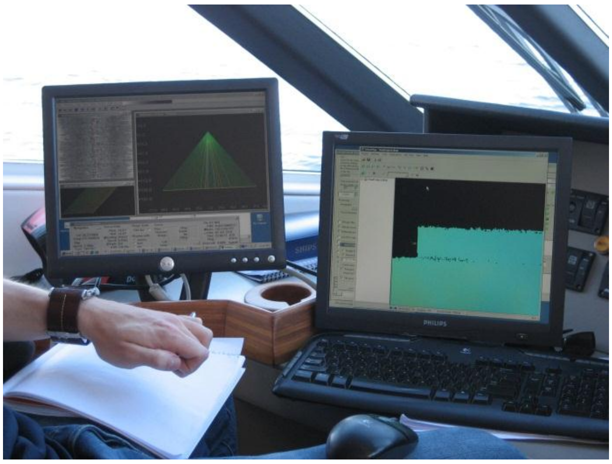
AUCKLAND MARINE DISPOSAL GROUND

MONITORING SERIES

REPORT 2 MULTIBEAM ECHOSOUNDER: SEAFLOOR GEOMORPHOLOGY

February 2011





2.1 BACKGROUND

In Coastal permit no. 555 granted by Maritime New Zealand (MNZ) in December 2009, Section 2-Post-disposal Monitoring / Part a.-Formation of a spoil mound requires '*Monitoring for identifying the topographic expression of the disposal mound*' using a Simrad EM3000 MBES (Maritime New Zealand, 2009, p.4). Under that condition, a multibeam echosounder (MBES) survey was undertaken in July 2010 at the study site 25 km east of Great Barrier Island following the disposal of ~4800 m^3 of dredged material from Pine Harbour Marina. The results of this survey are compared to a similar survey undertaken at the study site in September 2008 with the objective of identifying evidence of formation of a mound following the disposal events.

Following consultations, the disposal site boundaries were shifted so that the centre coordinates were a further 1000 m north and 1500 m east from the boundary of the Auckland CMA. Therefore, the pre-disposal survey limits of September 2008 do not completely overlie the survey limits of the post-disposal survey from July 2010, but the actual disposal coordinates are included in both surveys making possible comparison of the most relevant data (Figure 2.1). Additionally, the limits of the post-disposal survey were extended to include most of the area surveyed in the pre-disposal survey plus the added area not previously surveyed.

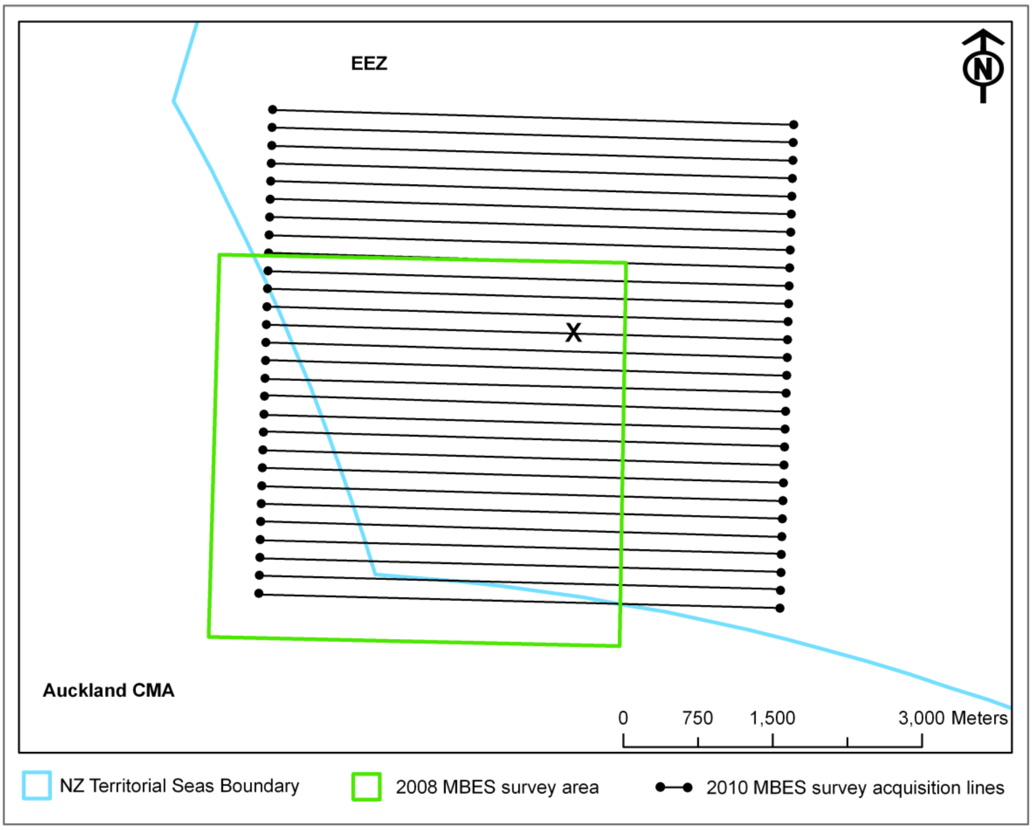


Figure 2.1 Acquisition lines used to navigate the vessel during the 2010 MBES survey. 'X' indicates the disposal location.

Disposal of the ~4800 m^3 of dredged material was undertaken in 9 loads (averaging ~540 m^3 per load) using a towed split hull hopper (Figure 2.2). The first and last loads were delivered at the site on March 14 and April 25 of 2010, respectively. The post-disposal MBES survey was completed on July 3, 2010.

Figure 2.2 Aerial photo of the tug MV Mina Campbell towing the split hull hopper 'Groper' to the disposal site for the second disposal on March 20, 2010 (photo: Terry Healy).

The MBES is an acoustic instrument designed to measure sea floor topography with very high accuracy (Lurton, 2002). This system is composed of a transmit array of transducers emitting an acoustic signal in direction of the seafloor, and of a receive array of transducers recording the signal reflected off targets in the water column or the seafloor. The principle for echo sounding in MBES is very similar to that of the single-beam echosounder (SBES) except for its formation of a high number of beams (up to 128 for the EM3000), in comparison to a unique beam for SBES, allowing for much denser coverage of the seafloor.

Beyond determining the bathymetry of the sea floor, MBES systems are being increasingly used to determine sediment composition of the sea floor through the processing of its signal amplitude (also termed backscatter) in a similar way as side-scan sonar (SSS) imagery (Hughes-Clarke *et al*., 1996; Preston *et al*., 2003; Beyer *et al*., 2007).

Multibeam bathymetry data show the variation in depths of the sea floor. The precision of the measured depth is dependent upon the transmitted frequency, sampling frequency, beam pointing angle, beam width, a technique used for bottom detection, and actual water depth. The EM3000 achieves in theory a measurement accuracy of 5 cm RMS in shallow water (Kongsberg, 2005). However, due to increased sound absorption and heterogeneous physical conditions of the water column over large distances, this precision can be significantly less in deeper waters like those encountered during this survey.

Multibeam backscatter data, like SSS imagery, typically show the variations in seafloor “hardness” and “roughness”. Backscatter Strength is the ratio between backscatter and incident sound intensity after reflection on the seafloor and is measured in decibels (dB). MBES backscatter data are processed into an imagery of the seafloor, which is like an “acoustic picture”. Due to lack of calibration in commercial MBES systems and processing corrections being applied to the data for “cosmetic” purposes, the dB values in MBES imagery are, like that of SSS imagery, purely indicative. However, the variations in imagery tone and texture are useful to identify and position transitions from one sediment type to another, to be confirmed afterwards through ground-truthing surveys. In a general manner, a harder and/or rougher seafloor will present higher backscatter strength.

2.2 METHODOLOGY

The post-disposal survey was undertaken using the Kongsberg (formally Simrad) EM3000 MBES (300 kHz) owned by the University of Waikato, Department of Earth and Ocean Sciences, Coastal Marine Group. The system was set-up on the MV Ten-Sixty, a vessel associated with the research project and readily accessible whenever weather conditions were ideal for the survey.

Set-up involved surveying the locations of the sonar head, GPS antenna, and motion sensor with respect to a reference point near the centre of the vessel and the water level on the vessel while in motion. These measurements were used to account for any offsets in the data once acquired.

Acquisition lines used to navigate the vessel during the survey were generated using Trimble HydroPro software based on the four corners of the site boundaries (175° 45’ 57.593” E, 36° 11’ 09.618”S; 175° 49’ 26.857”E, 36° 11’ 09.618”S; 175° 49’ 26.857”E, 36° 13’ 50.956”S; 175° 45’ 57.593”E, 36° 13’ 50.956”S) (Figure 2.1). The distances between acquisition lines were designated based on the swath width achieved in the 2008 MBES survey (~200 m). Some overlap was allowed in order to achieve maximum coverage and to account for expected noise at the outer beams as the system would be operating at its depth limits.

MBES data was acquired with Triton Imaging Inc. Isis software. Bathymetry data was processed with Triton Imaging Inc. Bathypro software and gridded at a 1 m resolution. Tides were removed from the MBES bathymetric data based on modelled tides which also accounted for the effects of forecasted atmospheric pressure. Backscatter data was processed using Hypack Geocoder software by which along-track banding effect was removed. Backscatter data was mosaicked at a resolution of 1 m.

2.3 RESULTS

2.3.1 MBES Bathymetry

The water depth ranges from approximately 135 m to 155 m across the total area surveyed in 2008 and 2010. The hydrographic contours run northwest to southeast and proceed in a gentle slope across the generally featureless shelf in this area. The MBES bathymetric datasets from 2008 and 2010 are consistent in that the contours align appropriately and the slope shows no great change between datasets (Figure 2.3). In the area of concern, the 1000 m X 1000 m area surrounding the location of disposal (H2), the water depth increases from approximately 141 m to 147 m (Figures 2.3 and 2.4). There is no obvious change in bathymetry in the area of H2 that would suggest the formation of a disposal mound, at least one with a great enough height to be detected by the Kongsberg EM3000 MBES at these depths.

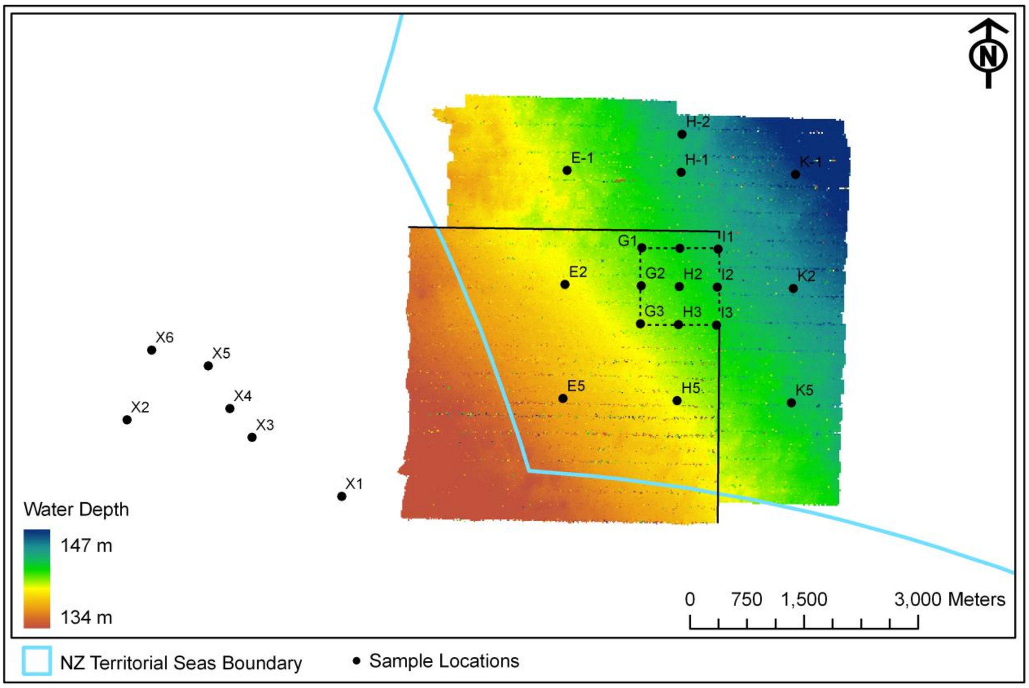


Figure 2.3 MBES bathymetry (2010 dataset overlain by 2008 dataset). Black solid line indicates the northern and eastern limits of the 2008 dataset. Black dashed line indicates the area highlighted in Figure 2.4. H2 is the location of the 9 disposals.

A close-up view of the 1000 m X 1000 m area surrounding H2 supports this finding (Figure 2.4). In Figure 2.4, white horizontal bands present in all 3 plots, represent areas where no data were acquired and indicate the limits of the swath. Vertical banding, most obvious in the 3rd plot, is the result of boat motions not completely accounted for in the processing steps. If a mound had formed, a shallower area indicated by a lighter green/yellow colour would be visible in the centre of the 2010 dataset plot (2nd plot; Figure 2.4). To confirm, the difference between the bathymetric datasets from 2008 to 2010 was calculated across the 1000 m X 1000 m area (3rd plot; Figure 2.4). No change between datasets would be indicated by a pale yellow across the plotted area. In this case, the teal colour indicating a positive 30 - 50 cm change in bathymetry is generally consistent across the plotted area. The error is likely to be associated in small part with set-up differences between the vessel used in the 2008 survey and the MV Ten Sixty used in the 2010 survey. Probably a more significant contributor to the error is seasonal and inter-annual sea level oscillations not accounted for in the processing of the bathymetric data (Figure 2.5). There is potentially a 10 – 15 cm sea surface height discrepancy between 2008 and 2010 (University of Colorado at Boulder, 2010). Most significant is that despite the generally uniform error, there is no localised difference in bathymetry in the plotted area which would be the case if a large disposal mound had formed.

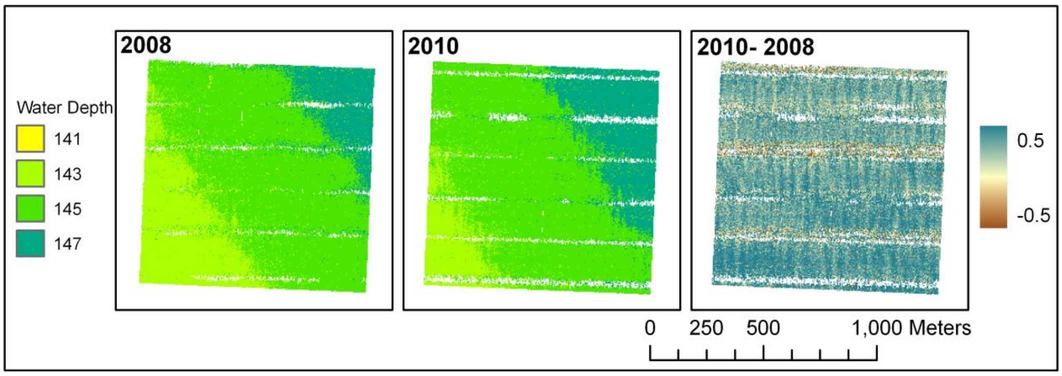


Figure 2.4 Close-up view of the bathymetry in the 1000 m X 1000 m area surrounding the disposal location, H2 (see Figure 2.3), pre- (2008) and post-disposal (2010). The 3rd plot illustrates the calculated bathymetric difference within the area from 2008 to 2010.

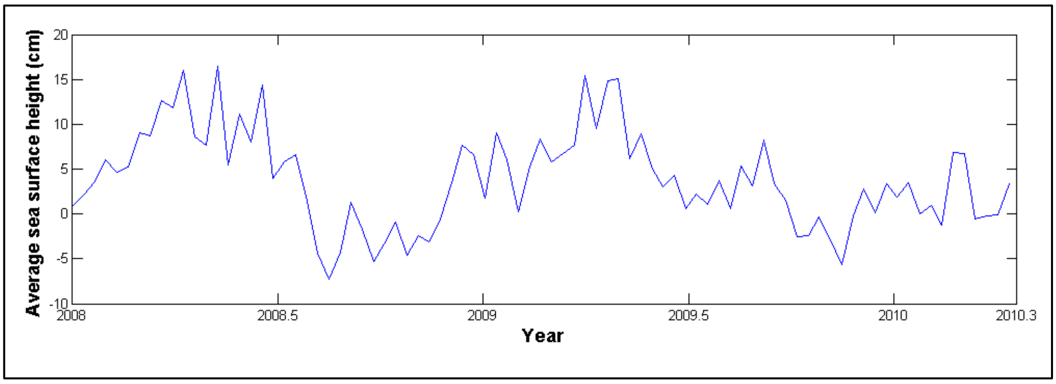


Figure 2.5 Average sea surface height in proximity to the study site (175E, 36S) between 2008 and the present (2010) (source: University of Colorado at Boulder, 2010).

To give a better idea of what sort of relief would be expected in this case, consider a circular area (because dredged material typically reaches the seafloor and then spreads out radially from the point of impact (Truitt, 1988)) with a diameter of 1000 m. The thickness of a layer from ~4800 m^3 of disposed material spread uniformly over the site would be 0.6 cm. If the same amount of material was spread over a circular area with a diameter of only 500 m, the deposited layer would be ~2.5 cm. In reality, the material would not be spread uniformly, but would be piled up more at the point of impact. In fact, cores taken from the disposal location (H2) did show a layer of dredged material 10 to 12 cm thick (see Report 1), but even this would not likely be detectable by the system in this case based on the associated errors.

2.3.2 MBES Backscatter

Although the disposed material did not deposit in a mound high enough to be measured as a bathymetric feature, MBES backscatter maps for the 2008 and 2010 survey show some indication the presence of the disposed material. In the 1000 m X 1000 m area surrounding the disposal location (see black dashed square in Figure 2.6), there is a visible change in backscatter intensity from 2008 to 2010. In the 2010 dataset, there is higher return intensity localised in the centre of the area which is indicated by a lighter grey colour not present in the 2008 dataset.

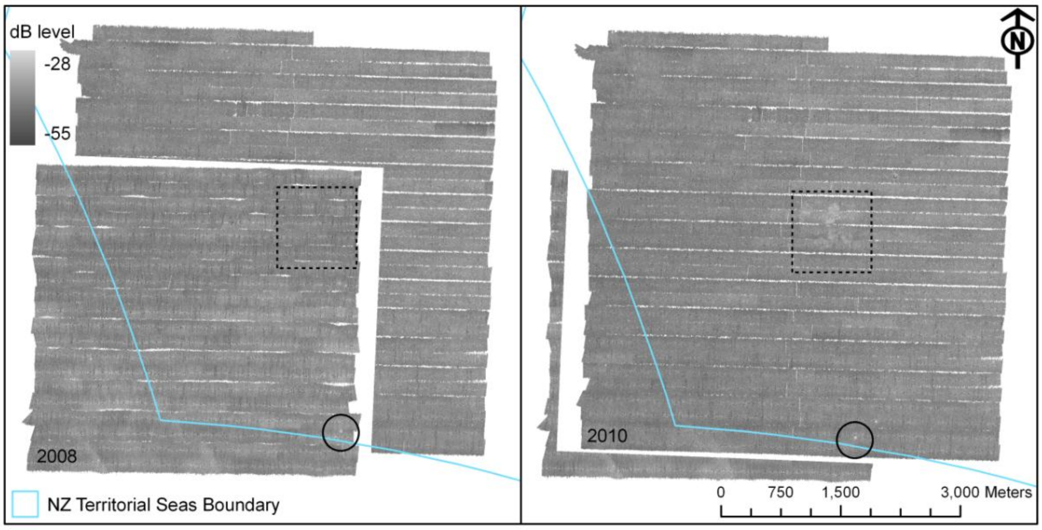


Figure 2.6 MBES backscatter. On left: 2010 overlain by 2008 and on right: 2008 overlain by 2010. Black dashed line indicates the 1000 m X 1000 m area surrounding the disposal location, H2 (see Figure 2.3). Black circle indicates a small feature with stronger reflectivity present in both datasets.

A close-up view of these areas shows multiple patches of this lighter grey colour in the 2010 dataset near the centre of the 1000 m X 1000 m area where the disposed material was known to have been released (Figure 2.7). A higher intensity return typically means that the substrate is either coarser or denser, and possibly both, than surrounding areas with lower intensity returns. In this case, clumps of densely packed material which are common products of the backhoe type dredging used in this case, are most likely what are causing a higher intensity return of backscatter in the area of the disposed material.

It is difficult to make out 9 distinct patches of higher intensity return substrate, but this is not unexpected as all 9 loads of dredged material were released and most likely landed in very close proximity to each other. What is significant to note is that there are no other areas in the 2010 dataset showing similar variability from the 2008 dataset. Additionally, none of the higher intensity return substrate seen in the 2010 dataset appears outside the 1000 m X 1000 m area surrounding the disposal location.

The majority of the remainder of the surveyed areas appear to have a uniform and relatively soft substrate consistent in both the 2008 and 2010 datasets which correspond well with the visual observations of the benthic cores (see Report 1). There is however, one other small feature indicating a higher intensity backscatter return (see feature highlighted in the black circle; Figure 2.6). This small feature is present in both surveys and is most likely some harder substrate such as a reef patch or anthropogenic object. As it is present and clear in both surveys, the variation observed in the disposal area in 2010 can be better qualified as valid and not just noise.

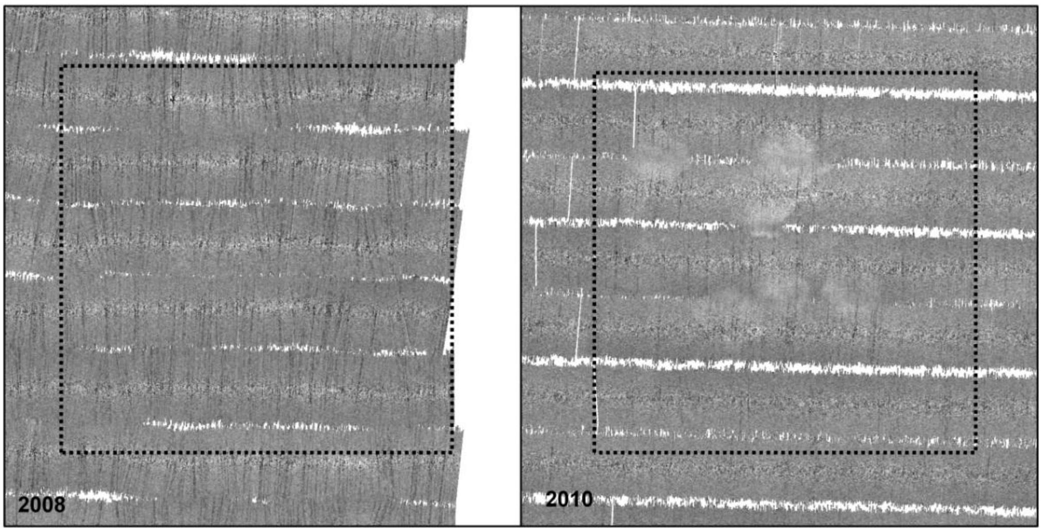


Figure 2.7 Close-up view of the 1000 m X 1000 m area surrounding the disposal location (indicated by the black dashed square) in the backscatter datasets from 2008 (on left) and 2010 (on right).

2.4 CONCLUSIONS

MBES bathymetry data revealed a gently sloping, mainly featureless seafloor that remained unchanged in the overlapping areas from the 2008 to 2010 surveys. There appears to be a consistent 30 to 50 cm error expressed as a change in water depth in the 1000 m X 1000 m area surrounding the disposal location which can be attributed to the change in system set-up as well as normal sea level oscillations. The expected thickness of sediment deposited on the seafloor after release of the trial volume of ~4800 m^3 is less than the error therefore it is not unexpected that a disposal mound in relief was not detected by the system.

MBES backscatter data more successfully illustrated at least the presence of the disposed material. In the 1000 m X 1000 m area surrounding the disposal location higher backscatter intensities were detected in multiple patches in the 2010 dataset than the same areas in the 2008 dataset. The higher backscatter intensities can most likely be attributed to denser clumps and therefore a coarser substrate in the areas were the dredged material deposited compared to the naturally occurring substrate which is soft and more uniform in nature.

Based on these findings, the following conclusions can be made:

i. The trial volume deposited did not form a mound high enough to be detected by the MBES system, based on bathymetric data alone;

ii. The material deposited is denser and/or coarser in nature than the naturally occurring substrate and was therefore detectable through analysis of MBES backscatter;

iii. No disposed material was deposited beyond the 1000 m X 1000 m area surrounding the disposal location (H2);

iv. Most of the disposed material appears to have been deposited within a 250 m radius of the disposal location; and *v.* These findings are consistent with visual observations of benthic cores (see Report 1).

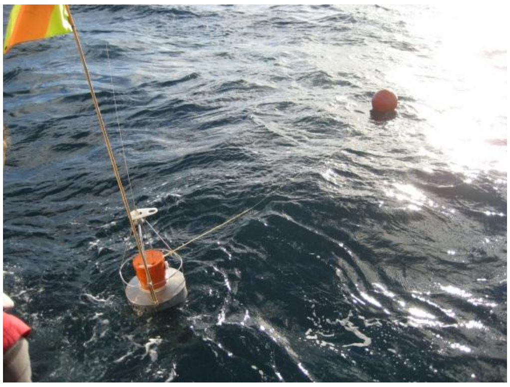
Conclusions based on MBES backscatter data need validation through ground-truth methods such as sediment sampling or underwater video. In this case, visual observations of pre- and post-disposal benthic cores are consistent with the localities of the disposed materials (see Report 1). Analyses of underwater video and geotechnical tests will be described in the following reports and will be used to further validate the substrate texture in the vicinity of the deposited material compared to that of the naturally occurring material.

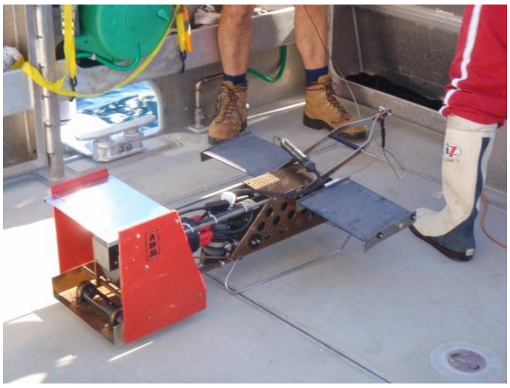
AUCKLAND MARINE DISPOSAL GROUND

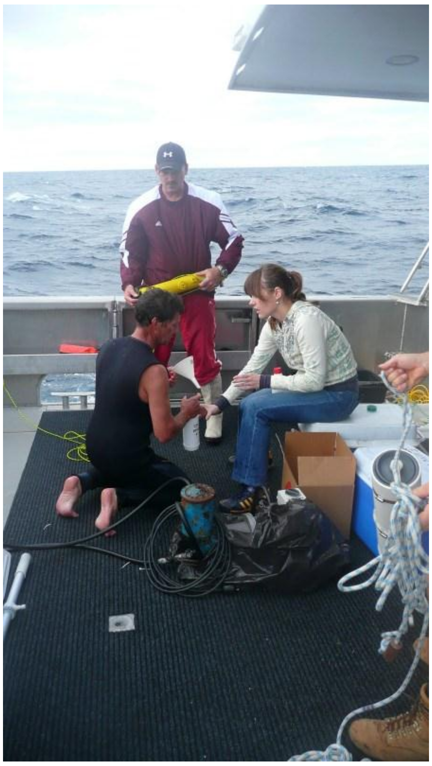
MONITORING SERIES

REPORT 3 PLUME MONITORING

February 2011







3.1 BACKGROUND

Test disposal operations were undertaken at the Auckland Marine Disposal Ground east of Great Barrier Island during the months of March and April 2010. During that time, 9 loads (average 540 m^3 each) of muddy dredged material from the basin of Pine Harbour Marina, Beachlands were transported to the centre of the site via tug and split hull hopper and released. The first load was disposed on March 14 2010 and the last on April 25 2010. On four of those occasions, the sediment plume associated with disposal operations was monitored by a University of Waikato monitoring team.

As a requirement of the consent conditions, plume monitoring data was collected on the 4 occasions mentioned above observe the site and its response to disposal operations under varying conditions including stage of the tide, wind, and sea state. The main objectives of these plume monitoring surveys were to determine the dispersion potential of the suspended sediment and whether or not it would disperse beyond the established boundary of the site, a 1500 m radius from the centre of the site (H2) (Figure 3.1). A secondary objective was to test the methodology used for monitoring the disposal plume to determine what was practical, both in terms of equipment and field implementation, in order to make recommendations for future monitoring.

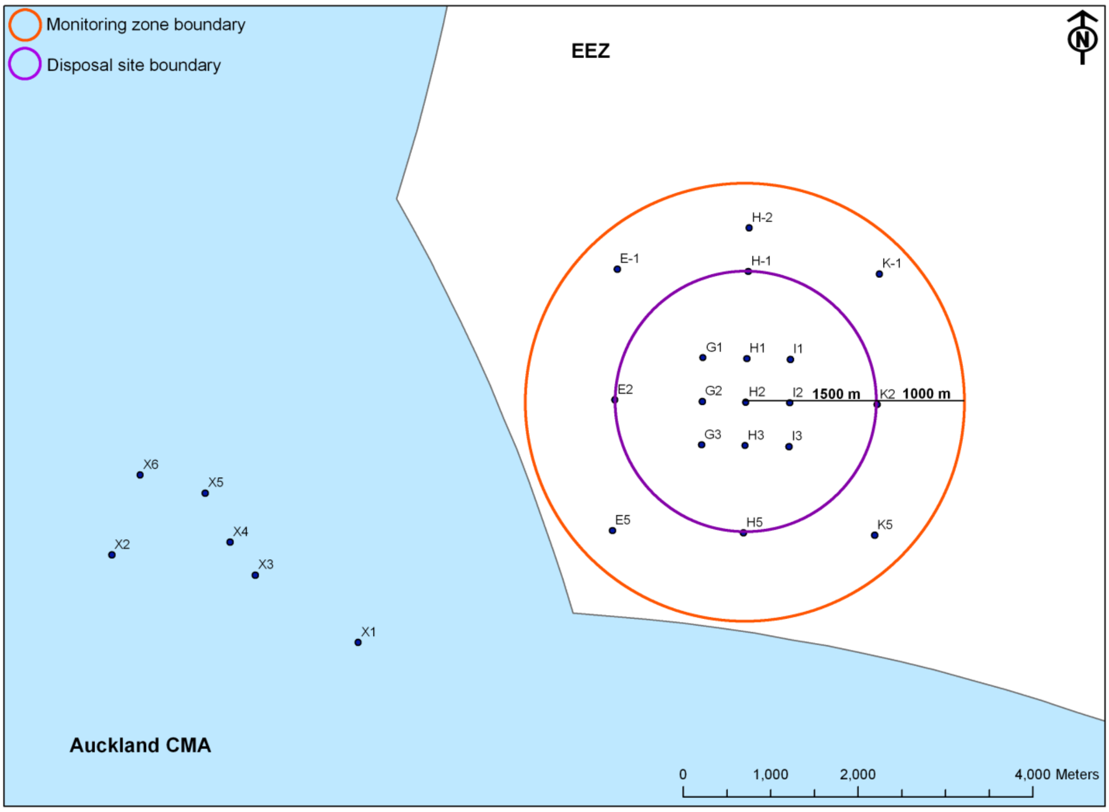


Figure 3.1 Map location of the proposed disposal site (purple circle), added monitoring zone (orange circle), and relevant sampling locations (including control sites X1-X6) visited before and after disposal operations in relation to the Territorial Seas and the Exclusive Economic Zone.

Surveys were limited to days of a relatively calm sea state due to the monitoring methods used. In general, this coincided with the sea state requirements of the tug and towed hopper used to transport the dredged material to the site. It has been shown that this method for transporting dredged material to a disposal site is more difficult in rough seas compared to other transport methods (USACE, 1983). Also, survey operations required daylight hours in order to visually track the surface plume. This included the need for several daylight hours before and after disposal to allow for set-up and break down of monitoring equipment. Due to weather and timing conflicts, the first survey took place on April 10 2010 following disposal number 6 at 11:07 am which, like all the disposal events, took place at the centre of the site (H2) (Fig 3.1).

Weather and sea conditions were recorded by both the survey team, as well as the skipper of the tug towing the split hull hopper containing the dredged material (Table 3.1). During Survey 1, the tide was flooding (though only just past slack tide), wind was tending southeast at 10 knots, and sea was slight with a 1 m swell towards the southeast. These wind and sea conditions were ideal for survey methods. Tide height for the month of April 2010 is shown in Figure 3.2 and Figure 3.3 shows the detailed stage of the tide on the day of each plume monitoring survey. The dotted lines indicate the approximate period during which disposal and surveys were undertaken.

Table 3.1 Summary of conditions during each of the 4 plume monitoring surveys.

Survey	Date	Time	Tide	Wind	Seastate
1	April 10 2010	11:07 am	Early flood	SE 10 knots	Slight; 1m swell towards SE
2	April 15 2010	10:02 am	Mid ebb	SW 10-15 knots	1 m seas from the SW; wind chop strong
3	April 21 2010	10:04 am	Mid to late flood	SW 5 knots	Calm; 0.5 m swell from the SW
4	April 25 2010	10:33 am	Early flood	NE 10 knots	variable

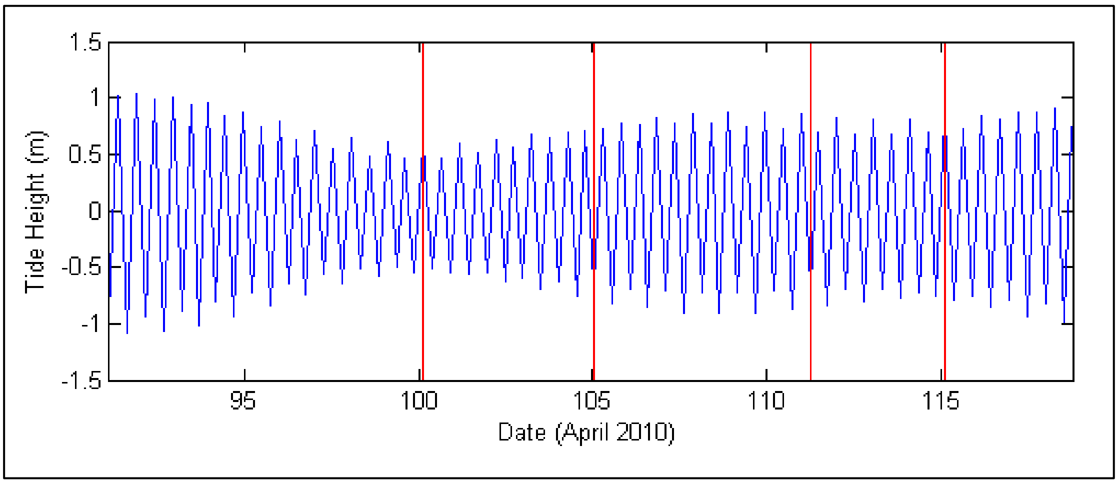


Figure 3.2 Tide height for April 2010. Red lines indicate the 4 plume monitoring days (source: National Institute of Water and Atmospheric Research (NIWA) tide model).

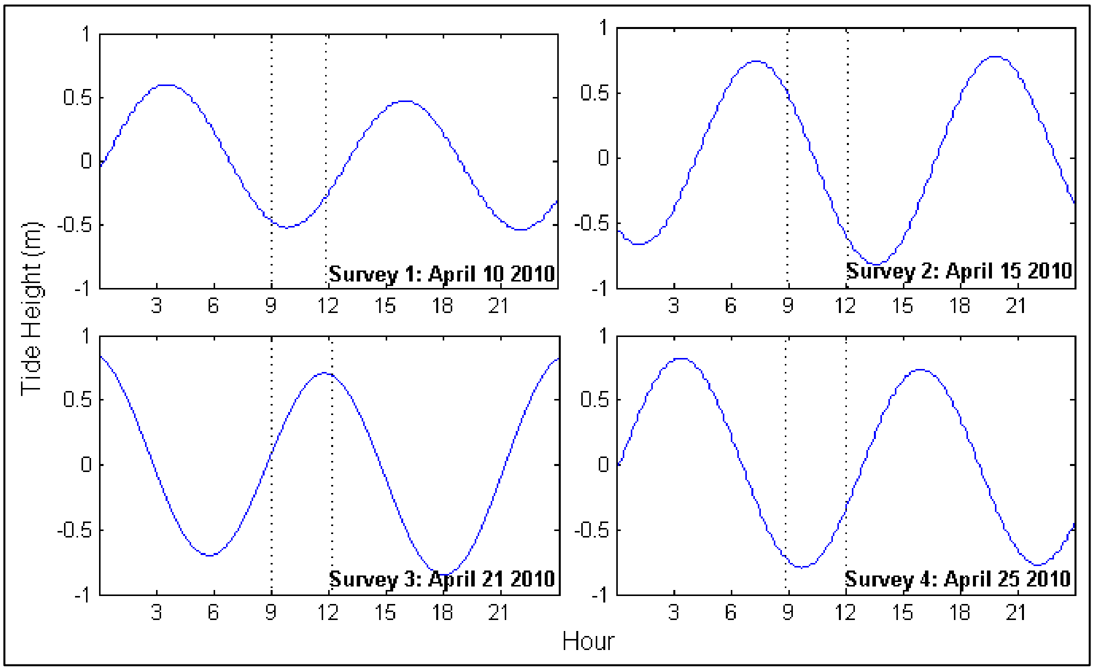


Figure 3.3 Tide height on the day of each plume monitoring survey. Approximate survey period indicated by dotted line (source: National Institute of Water and Atmospheric Research (NIWA) tide model).

Survey 2 was undertaken on April 15 2010 following disposal 7 at 10:02 am. Conditions were less ideal for plume monitoring with wind tending southwest at 10-15 knots with 1 m seas from the southwest. Tide in this case was ebbing (Figure 3.3). Wind chop was more severe during Survey 2 which resulted in some last minute changes to the survey plan (to be described below). Survey 3 was undertaken on April 21 2010 following disposal 8 at 10:04 am. Conditions were calm with winds tending southwest at 5 knots and 0.5 m seas from the southwest. Tides were flooding (Figure 3.3). During Survey 4, following disposal at 10:33 am on April 25 2010, conditions were variable, but winds tended northeast at 10 knots and the sea was relatively calm. Tide was flooding (though only just past slack tide) (Figure 3.3).

Weather and sea conditions undoubtedly had a major influence on fate and dispersion on the disposed material, but the type of material (silty clay), the methods employed for dredging, as well as the disposal technique also must be factored in. Throughout operations, the muddy marina basin sediment was dredged using a backhoe digger and placed into a split hull hopper for later disposal. Material dredged using a backhoe tends to retain some of its *in situ* structure in the form of large dense clumps or blocks, and as a result the water content of the material destined for disposal is lower than that dredged via alternate methods (USACE, 1983). However, as the material in this case was mainly fine in size, during dredging and placement in the hopper, some degree of agitation and mixing would be expected to occur. Depending on the length of time the full hopper remained at the marina and also the sea state during transport to the site, the material could be expected to undergo either some degree of consolidation increasing its strength/density or further agitation and mixing which would decrease its strength/density.

Upon arrival at the disposal site, release of the material was initiated as the hopper was towed over the agreed upon disposal coordinates. A small degree of error in the position of the hopper was expected as it was estimated based on the GPS coordinates of the tug which was some distance away. During disposal, the tug travelled from east to west past the disposal coordinates and maintained a speed of ~2 knots throughout release which took no more than several seconds.

3.2 METHODOLOGY

Methods used in each of the four plume monitoring surveys were in compliance with consent conditions. Though logistical problems (e.g. weather, equipment) did result in some loss of data, each survey was undertaken as close to possible in accordance with the consent requirements.

On each of the four surveys, drifter observations made prior to the arrival of the towed hopper were used to decide the locations of the monitoring stations. Once determined, stations were moved into place and set-up to await the arrival of the towed hopper. Typically, stations consisted of two assisting fishing vessels and one small manned rubber dingy each anchored at a designated location (Figure 3.4). It was intended that the two fishing vessels (hereafter Stations A and B) would be positioned so that they would be close to or in the eventual disposal plume. The small manned rubber dingy (hereafter Station C) was to be positioned further away in an area where the plume was not expected to go allowing for collection of “ambient” conditions data. Each vessel was equipped with the required monitoring equipment and prior to disposal two monitoring team assistants aboard each vessel prepared the monitoring equipment by suspending weighted turbidity sensors over the side at designated depths. On Survey 1, a fourth unmanned station (hereafter Station D) was also deployed prior to arrival of the towed hopper with equipment programmed to a designated start and end time, however due to time constraints and feasibility of deploying the unmanned station, it was not used in the remaining surveys. Also, in Survey 2, weather conditions were unsafe for deployment of the small manned rubber dingy, so “ambient” conditions were recorded/sampled for aboard the main survey vessel at the centre of the site (H2) prior to the arrival of the towed hopper.

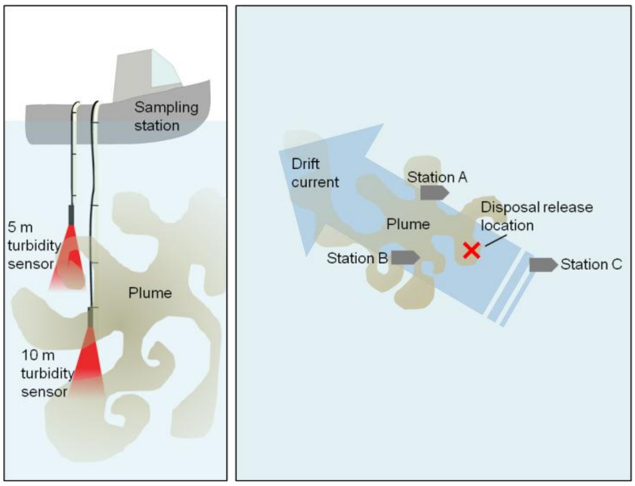


Figure 3.4 Diagram of sensor deployment from each sampling station (left) and a top view of station arrangement in relation to the expect direction of plume dispersal (right).

Using radio communications, teams on all three vessels were instructed to turn the sensors on approximately 5 min prior to disposal. As soon as sensors were turned on, water sampling began at each of the stations. During this time, the main survey vessel would get in place to begin surveying using the ADCP and the Biofish (to be described below) as soon as the empty hopper was towed out of the way. Surveys were carried out for approximately 1 hour following release of the dredged material into the water column. Surveying was terminated when it became too difficult to discern the plume from the surface.

3.2.1 Conductivity/Temperature/Density (CTD)

On each of the four plume monitoring surveys, a “SeaBird” CTD profiler was deployed near the disposal release location immediately following completion of plume monitoring (as the vessel must be stationary for deployment). This device includes sensors which record conductivity (from which salinity can be inferred), temperature, and density with respect to depth (Figure 3.5). Two to three profiles were recorded during each survey in locations relevant to plume locations observed during the monitoring portion of each survey. It should be noted that often the plume itself was significantly diluted and dispersed by the time the CTD profile was recorded, but stratification of the water column, if present, would be detectable regardless of the presence of the plume. CTD profile locations visited after each survey are listed in Table 3.2.

Figure 3.5 “**Sea Bird” CTD profiler used to record conductivity, temperature and density at the site following completion of each of the four plume monitoring surveys.**

Table 3.2 Locations of recorded CTD profiles following each of the four plume monitoring surveys (refer to Figure 3.1 for site locations).

Survey	CTD profile locations
1: April 10 2010	H1, H2, I2
2: April 15 2010	H2, I1
3: April 21 2010	H2, H2/I2*, I2
4: April 25 2010	H2, I2, G2

*H2/I2 represents a location half way between sites H2 and I2

3.2.2 Drogues (Drifters)

Drogues attached to surface buoys housing GPS transmitters and set to water depths of 10 and 30 m (called drifters) were deployed at the centre of the site (H2) prior to disposal on each of the four plume monitoring surveys (Figure 3.6). Drifters were left in the water for approximately 1 hour while GPS coordinates of each were received and recorded on the main survey vessel allowing for estimation of predominant current direction and velocity on the day of each survey. Coordinates were transmitted approximately every 5 min giving satisfactory resolution to the drifters' paths. Prior to arrival of the towed hopper, drifter observations were used to make decisions on where monitoring stations would be positioned to best monitor the plume. It should be noted however that often 2 or more hours passed between drifter deployment and plume monitoring allowing time for changes in the current, especially with respect to the tide, that may not have been reflected in the drifters' paths.

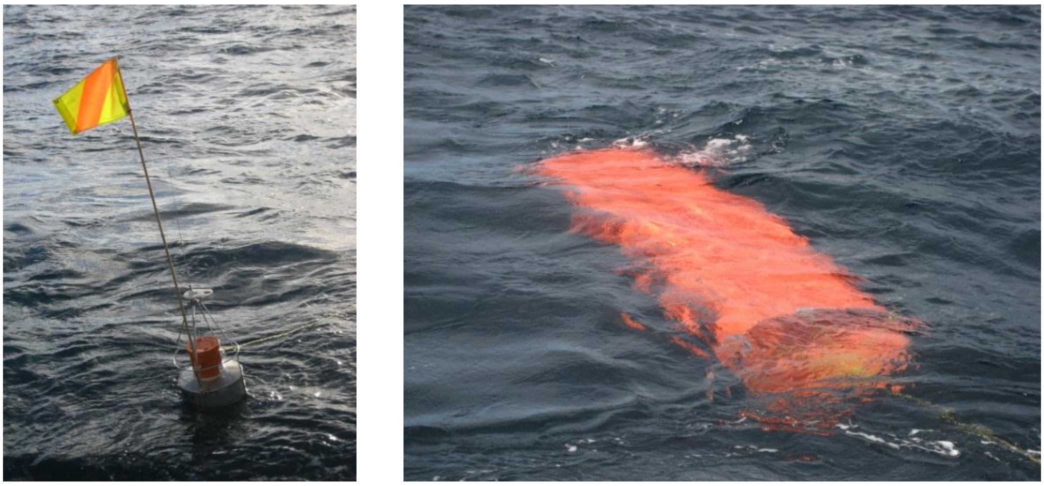


Figure 3.6 Images of the drifter buoy housing a GPS transmitter (left) and drifter sail (right) immediately after deployment (as the hollow frame of the sail fills with water, it sinks to the designated depth).

On Survey 1, four drifters were deployed, two each at 10 and 30 m water depth. Due to time constraints involved in deployment and retrieval of the drifters and preparation of monitoring equipment in anticipation of the arrival of the towed hopper, for the remaining surveys, it was decided that only two drifters would be deployed, one each at 10 and 30 m water depth.

3.2.3 Water samples

On each of the four surveys, water samples were collected at Stations A, B, and C at 5 and 10 m water depths (Figure 3.7). Sampling began approximately 5 min prior to release of the dredged sediment from the split hull hopper and was carried out at each depth every 5 min after that for the length of the survey. Sampling was undertaken for about an hour on each survey and was stopped after the surface plume was no longer visible. Sampling periods are listed in Table 3.3. Due to the transient nature of the surface plume, Stations A and B were not always located directly in the disposal plume as the appropriateness of the location chosen for each station could only be judged based on visual observations from the surface. During Survey 1, Stations A and B were discovered to be located mainly at the southern end of the plume and should have been preferably situated closer together. A similar scenario arose on Survey 2 as well. To compensate for this miscalculation, during Survey 2, Stations A and B were relocated (new locations labelled Stations A2 and B2, respectively) (Figure 3.7). The move did allow for sampling directly in the plume, however technical difficulties encountered during the shift to the new sites resulted in only approximately 10 min of water sampling in the new locations.

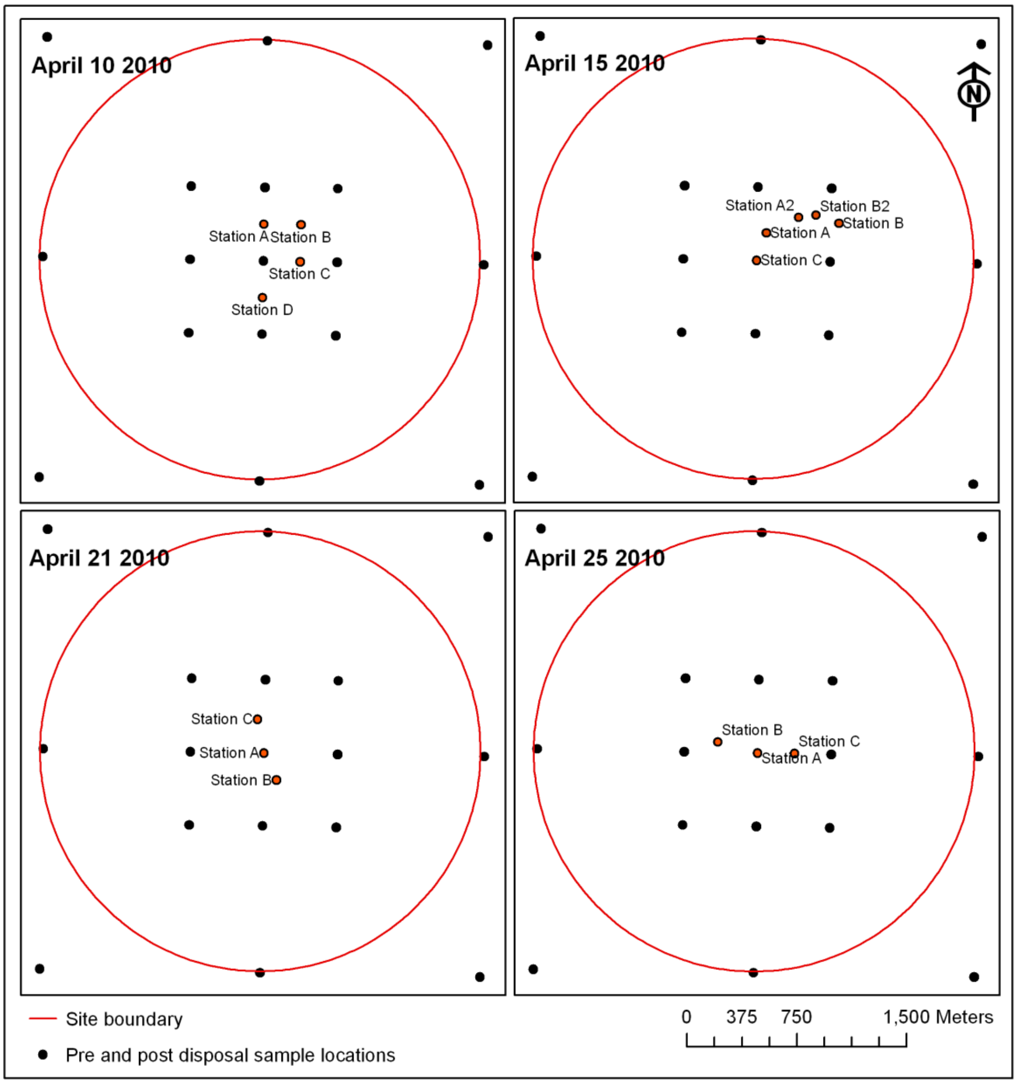


Figure 3.7 Locations of plume monitoring stations A, B, C, and D on Survey 1: April 10 2010, Survey 2: April 15 2010, Survey 3: April 21 2010, and Survey 4: April 25 2010.

Table 3.3 Water sampling period at each station during each survey. Samples were collected every 5 minutes for the length of the survey.

Survey	**Disposal time**	**Water sampling period**		
		Station A	Station B	Station C
1: April 10 2010	11:07 am	11:00-11:55 am	11:00-11:55 am	11:00-11:55 am
2: April 15 2010	10:02 am	9:55-11:25 am	9:55-11:20 am	8:30-9:10 am
3: April 21 2010	10:04 am	10:07-11:17 am	9:57-11:17 am	9:57-11:17 am
4: April 25 2010	10:33 am	10:35-11:40 am	10:25-11:40 am	10:25-11:30 am

Water samples were collected simultaneously at 5 and 10 m water depths using either "Niskin" and "Van Dorn" style samplers or "Schindler-Patalas" traps. Niskin and Van Dorn samplers consist of cylindrical bottles with end caps. To use, the caps are set open and the device is lowered down to the specified depth. Next, a lead weight is sent down the cable which upon reaching the bottle, hits a release mechanism that induces the end caps to snap shut trapping water inside the bottle from the desired depth. Schindler-Patalas traps are similar in that the compartment closes at either end only at the desired water depth, but the mechanism is slightly different. In this case, the compartment is rectangular with trap doors at the top and bottom that only move in the upward direction. This is so that as the trap is lowered to the desired depth, the trap doors swing up allowing water to flow freely through the compartment. At the specified depth, the backwards motion of the trap as it is being pulled back up causes the doors to swing shut effectively trapping water from the desired depth inside the compartment. Both types of samplers have an opening in the side of the compartment where the collected water can be extracted into a container for later analysis. For these surveys approximately 1 L of water was retained from each sample and stored on ice.

Following each survey, known volumes of the water samples were filtered through pre-rinsed, dried, and weighed filters to collect suspended particles (APHA, 1997). The labelled filters were then dried for 24 hours at 105°C and the re-weighed. The following formula was then used to calculate suspended sediment concentration (mg/L):

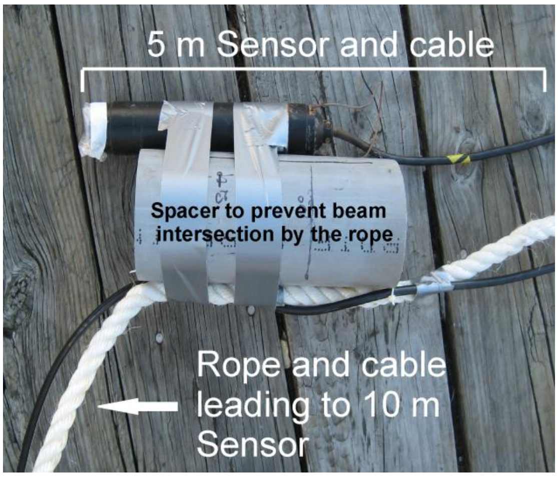
$$[(w_2 - w_1)1000]/v$$

where w_1 is the weight (g) of the rinsed and dried filter paper, w_2 is the weight (g) of the re-dried paper following filtration, and v is the volume (L) of sample filtered (APHA, 1997).

3.2.4 Turbidity Sensors

At each of the stations A, B, and C (and Station D on Survey 1) (Figure 3.7), turbidity sensors were deployed at 5 and 10 m to coincide with water sampling depths (see above). During some of the surveys, sensors were added at different depths to increase data coverage and to provide back up for some sensors that were less reliable. Table 3.4 details the turbidity sensor deployments on each of the four surveys and each station. In general, the aim of the sensor deployment was to record time series of turbidity levels in and near the plume as well as in “ambient water” and at two different water depths. Sensors were suspended off the assisting vessels on lines at 5 and 10 m with cables attached to loggers and batteries in water tight containers at the surface (Figure 3.7). Each container was equipped with a power switch so that the sensors could be deployed well in advance without the necessity of recording extraneous data. Using radio communication from the main survey vessel, assistants were told when to turn on and off the sensors. This method also preserved battery power. Some of the sensors functioned with internal loggers and an internal power source. These sensors were programmed the morning of each survey to power on and off at the appropriate times.

Turbidity is a measurement of the transparency of the water which is directly proportional to the number of particles suspended in that water (Davies-Colley and Smith, 2001). So, although turbidity is not a direct measurement of suspended solids concentration, this value can be inferred and closely estimated through calibration procedures. Turbidity sensors are essentially optical sensors and function by measuring the amount of light scattered or the amount of light absorbed/attenuated by suspended particles through the use of a light source and a photo-detector (Davies-Colley and Smith, 2001). The photo-detector converts the light radiated by the water into a photocurrent usually in units of volts (V) or amperes (amps). The light radiated by the water is dependent on the number of particles, size of particles, shape of particles, orientation of particles, colour, and reflection index. Individual turbidity sensors are usually designed to function in a set range of turbidity with maximum and minimum voltage outputs.



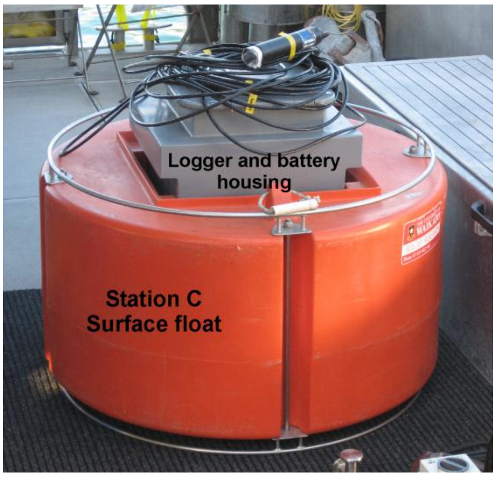


Figure 3.8 Sensor deployment configuration. Left: 5 m sensor attached to a rope with a second cable leading to the sensor attached at 10 m (spacer prevents light beam intersection by the rope). Right: a surface float for Station C containing the water tight logger and battery housing from which the sensors were suspended (note: Stations A & B housings' were secured on deck of the assisting survey vessels).

During the four plume monitoring surveys, a variety of sensors were used, each with different specifications and functions (Turner Designs, 2002); Campbell Scientific, 2008; Greenspan Technology). Prior to the field surveys, tests were done on the sensors to determine their applicability for the presumed level of turbidity that would arise following release of dredged material at the site. Only in the case of Sensor 9, was the maximum range surpassed during the surveys. Sensor 9 was deployed during Surveys 3 and 4 as a replacement for a lost sensor and due to time constraints, full testing prior to deployment was not performed.

Table 3.4 Summary of turbidity sensor deployment during each of the 4 plume monitoring surveys.

Survey date	Disposal time	Station	Station type	Sensor number	Depth (m)	Usable data	Sampling interval (s)
April 10 2010	11:04 am	A	Suspended from assisting fishing vessel	1	5	None	N/A
				2	10		
		B	Suspended from assisting fishing vessel	3	5	10:59 -11:54 am	1
				4	10		
		C	Suspended from manned rubber dingy	5	5	11:00-11:54 am	9
				6	10		
		D	Suspended from unmanned rubber dingy	7	5	None	N/A
				8	10	9:50-12:36 am	1
April 15 2010	10:00 am	A	Suspended from assisting fishing vessel	1	5	None	N/A
				8	7	9:50-9:55 am 10:04-10:56 am 11:15-11:26am	1
				2	10	None	N/A
		B	Suspended from assisting fishing vessel	3	5	11:07-11:15 am	1
				4	10		
		C	Suspended from main survey vessel before disposal	5	5	8:32-9:09am	9
				6	10		

April 21 2010	10:02 am	A	Suspended from assisting fishing vessel	2	1	None	N/A
				1	5		
				9	7	10:00-10:34 am 10:40-11:14 am	1
				8	10	10:07-11:15 am	1
		B	Suspended from assisting fishing vessel	7	5	None	N/A
				10	7	None	N/A
				4	10	9:52-11:20 am	1
		C	Suspended from manned rubber dingy	5	5	10:00-11:20 am	9
				6	10		
April 25 2010	10:30 am	A	Suspended from assisting fishing vessel	2	1	None	N/A
				1	5	None	
				9	5	10:38-11:04 am 11:10-11:44 am	1
				8	10	10:36 -11:45 am	1
		B	Suspended from assisting fishing vessel	7	5	None	N/A
				10	7	None	N/A
				4	10	10:28-11:44 am	1
		C	Suspended from manned rubber dingy	5	5	None	N/A
				6	10		

In general, each sensor was programmed to take 1 reading per second and record data in raw units. In most cases, data was recorded in millivolts (mV), with the exception of Sensor 9 which recorded in volts (V) and Sensor 8 which was pre-calibrated using Formazin standards allowing for direct conversion of the recorded photo current into Nephelometric Turbidity Units (NTU). Table 3.5 shows the details of sensors which recorded usable data.

Table 3.5 System details of deployed turbidity sensors (sensors which did not record usable data are not included).

Sensor No.	Brand/Model	Data Logger	Measurement type	Range		Recorded units
				Raw	NTU	
3	Greenspan TS100	Campbell Scientific	Optical backscatter	4-20 mA	0-2000	millivolts
4	Greenspan TS100	Campbell Scientific	Optical backscatter	4-20 mA	0-2000	millivolts
5	Greenspan TS100	Campbell Scientific	Optical backscatter	4-20 mA	0-2000	millivolts
6	Greenspan TS1200	Campbell Scientific	Optical backscatter	4-20 mA	0-2000	millivolts
8	Scufa	Internal	Optical backscatter	0-5V	0.05-200	NTU
9	OBS-3	DOBIE	Optical backscatter	0-5V	0-50	volts

Following the plume monitoring surveys, the turbidity data was scaled to suspended sediment concentration (mg/L) using calibration coefficients determined by comparing sensor readings to known concentrations of marina basin sediment added progressively to continuously circulating water in a calibration tank. Details of the calibration procedure are included in the Appendix.

3.2.5 BIO-FISH

BIO-FISH is a vessel towed multi-sensor probe linked to a PC system on deck where data are recorded (Figure 3.9) (ADM Elektronik, 2003). BIO-FISH has wings that can be controlled from the PC system where wing-angle can be adjusted to allow undulation of the fish at desired intervals and water depths behind the boat.

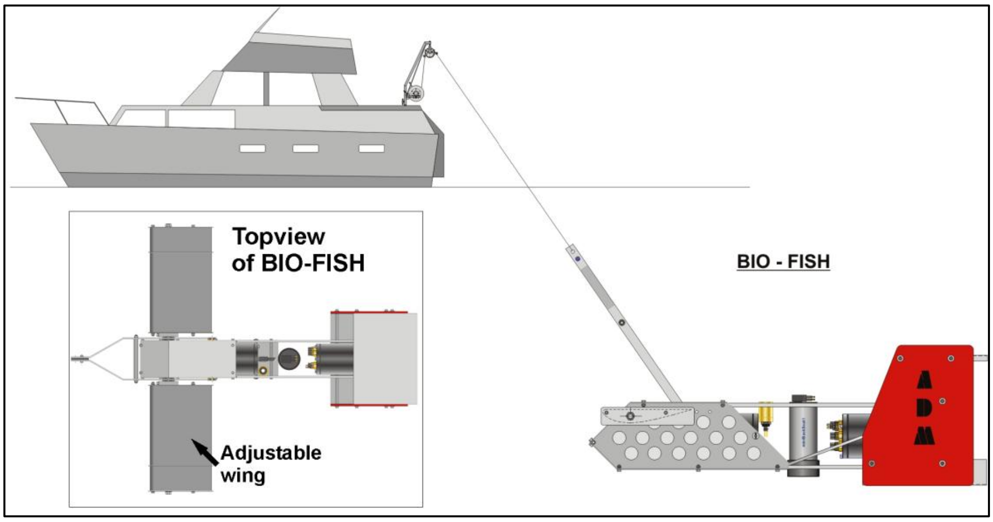


Figure 3.9 BIO-FISH deployment configuration (inset: top view showing adjustable wings that allow for vertical undulation of the fish).

BIO-FISH is equipped with a turbidity sensor called a transmissometer. Unlike measurement by turbidity sensors described in the previous section, a transmissometer measures beam attenuation which is also proportional to the quantity and type of suspended particles in the water column (Davies-Colley and Smith, 2001). BIO-FISH was towed from the main survey vessel on Surveys 3 and 4 for entire survey period. On Survey 3, BIO-FISH was undulated between approximately 5 m and 25 m below the surface for the length of the survey. On Survey 4, BIOFISH was undulated between approximately 10 m and 20 m below the surface for the length of Survey 4. Data was recorded as one continuous transect.

3.2.6 Acoustic Doppler Current Profiler (ADCP)

ADCPs are traditionally used to measure current velocity based on the principle of the Doppler frequency shift of a moving object (Figure 3.10). However, using acoustic backscatter intensity, turbidity and thus suspended sediment concentration can also be inferred from these devices (Figure 3.10) (Gartner and Cheng, 2001). There are some limitations to this method (e.g. range of detected particle sizes; change in concentration is indistinguishable from change in particle size), but in general it can be very effective in detecting suspended particles. In the case of monitoring a plume, vessel mounted ADCPs can provide not only temporal turbidity data, similar to stationary turbidity sensors, but also data indicative of the spatial extent of the plume. Spatial data is dependent on the path of the vessel in that it must be relevant to the area of the plume.

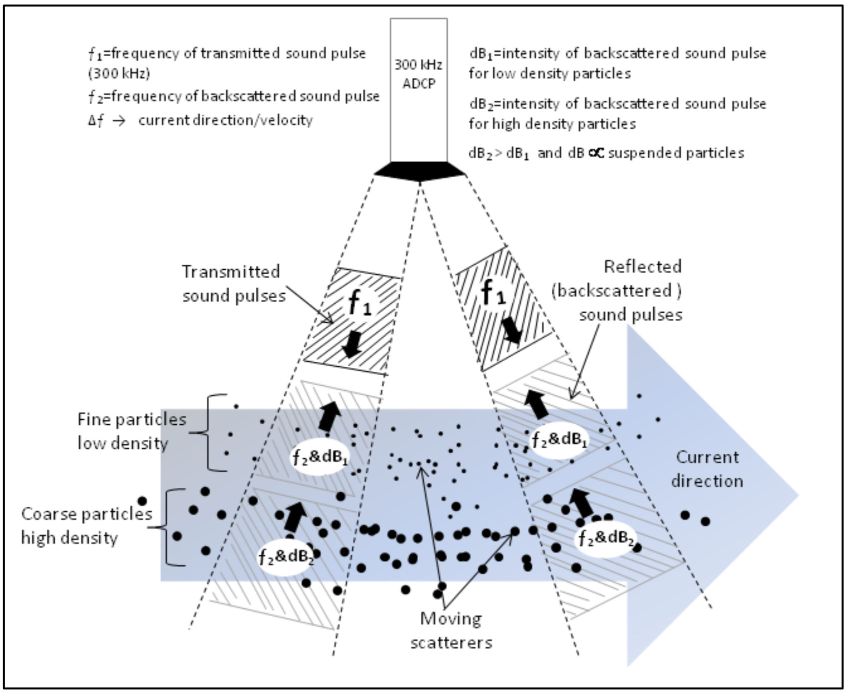


Figure 3.10 Diagram of ADCP "Doppler" frequency (*f*) shift principle and backscatter intensity (dB) relationship to suspended particles.

On each of the four plume monitoring surveys, a 300 kHz "RDI" ADCP was mounted to the main survey vessel (Figure 3.11). This device was operated using dedicated PC-interfaced software in conjunction with Differential Global Positioning System (DGPS) to obtain geo-referenced backscatter intensity data as the vessel was navigated in the area of the disposal plume. Table 3.6 details the ADCP transects recorded during each of the four surveys.

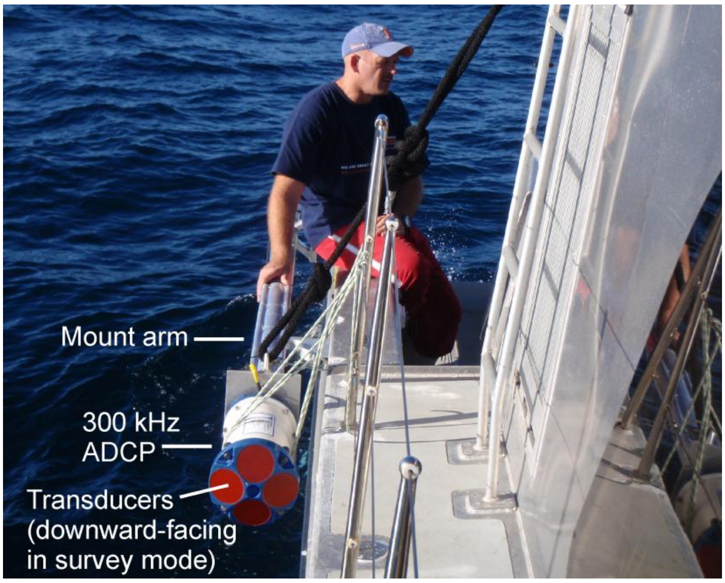


Figure 3.11 Photo of the 300 kHz RDI ADCP mounted to the main survey vessel during one of the plume monitoring surveys. When not in survey mode, the mount arm is swung up out of the water to protect the device.

As reported by the manufacturer, this device is capable of recording data in water depths up to approximately 150 m which is the approximate maximum depth at the eastern boundary of the disposal site. However, achieving maximum resolution at those depths is dependent on deployment factors such as power supply, cable length, and appropriate user settings. By applying the Rayleigh (long wavelength) scattering model, the appropriateness of the device for inferring turbidity levels can also be determined (Gartner and Cheng, 2001). This theory is based on the particle size distribution and the frequency of the ADCP (300 kHz in this case). The model says that backscatter intensity will be most representative where the ratio of the particle circumference to the wave length of the acoustic signal is less than 1 or

$$[2\pi r/\lambda]<1 \quad \text{and} \quad \lambda=c/f$$

where r is the radius (m) of the particle, λ is the wavelength (m) of the acoustic signal, c is the speed of sound (m/s) in water (~1500) and f is the frequency (Hz) of the acoustic signal. Also, where the above ratio is less than ~0.01, backscatter intensity is less representative of the suspended particles present. Within those ranges and with respect to the frequency of the ADCP used (300 kHz), the particle size distribution that will be best represented by the backscatter intensity data is approximately 15 µm – 1.5 mm or medium sized silt to very coarse sand (after Udden-Wentworth scale). In this case, representation of sediment size classes outside this range may not be as robust. However, flocculated clay-sized particles are effectually larger than individual clay particles and would likely be registered by the ADCP system.

Table 3.6 Summary of ADCP transects for Surveys 1-4.

Disposal time			11:04 am				10:00 am				10:02 am				10:30 am
Date	**Transect**	**Start**	**Finish**	**Date**	**Transect**	**Start**	**Finish**	**Date**	**Transect**	**Start**	**Finish**	**Date**	**Transect**	**Start**	**Finish**
10-Apr-10	1	8:34	8:37	15-Apr-10	1	10:02	10:04	21-Apr-10	1	9:13	9:13	25-Apr-10	1	10:33	10:35
	2	8:37	8:41		2	10:04	10:04		2	10:07	10:09		2	10:35	10:37
	3	8:42	8:42		3	10:05	10:07		3	10:10	10:12		3	10:37	10:40
	4	8:43	8:47		4	10:07	10:09		4	10:13	10:15		4	10:41	10:42
	5	11:03	11:07		5	10:09	10:10		5	10:17	10:19		5	10:42	10:44
	6	11:07	11:09		6	10:11	10:12		6	10:19	10:22		6	10:45	10:50
	7	11:09	11:12		7	10:12	10:13		7	10:23	10:29		7	10:51	10:55
	8	11:12	11:15		8	10:14	10:15		8	10:29	10:30		8	10:56	11:02
	9	11:15	11:16		9	10:16	10:19		9	10:30	10:38		9	11:03	11:09
	10	11:17	11:19		10	10:20	10:21		10	10:40	10:51		10	11:10	11:12
	11	11:20	11:21		11	10:21	10:24		11	10:53	10:54		11	11:14	11:15
	12	11:22	11:24		12	10:25	10:28		12	10:55	10:57		12	11:17	11:19
	13	11:25	11;26		13	10:29	10:34		13	10:59	11:00		13	11:20	11:25
	14	11:27	11:28		14	10:34	10:37		14	11:00	11:02		14	11:26	11:29
	15	11:30	11:33		15	10:38	10:42		15	11:02	11:04		15	11:31	11:34
	16	11:33	11:36		16	10:43	10:46		16	11:05	11:07		16	11:36	11:38
	17	11:36	11:39		17	10:47	10:50		17	11:07	11:23		17	11:38	11:41
	18	11:39	11:42		18	10:51	10:51		-	-	-		-	-	-
	19	11:43	11:45		19	10:53	10:54		-	-	-		-	-	-
	20	11:45	11:47		20	10:55	10:56		-	-	-		-	-	-
	21	11:47	11:48		21	11:10	11:12		-	-	-		-	-	-
	22	11:49	11:51		22	11:12	11:13		-	-	-		-	-	-
	23	11:52	11:54		23	11:14	11:16		-	-	-		-	-	-
	24	11:54	11:58		24	11:16	11:18		-	-	-		-	-	-
	-	-	-		25	11:20	11:21		-	-	-		-	-	-
	-	-	-		26	11:22	11:23		-	-	-		-	-	-

3.3 RESULTS

Survey results for each of the four plume monitoring surveys have been compiled by survey method so that the effect of the weather and sea conditions on the plume on each day can be more easily compared. In general, the data reported is that which bears the most relevance to the objective of the surveys, which is to determine the patterns of plume dispersion after open-water disposal of muddy dredged material.

3.3.1 Conductivity/Temperature/Density (CTD)

On each of the four survey days, CTD profiles were recorded at 2 to 3 sites immediately following the monitoring of the plume. Profiles were recorded at the centre of the disposal site (H2) after each survey and typically at one or two alternate sites nearby; at sites where the plume was prevalent during the monitoring. Generally, by the time the profiles were recorded the plume was dilute and not clearly visible from the surface.

Figure 3.12 shows the profiles recorded on each of the four surveys at Site H2 (location of release of dredged material). On all four days, a well-mixed surface layer was present that varied in thickness from approximately 30-80 m. In the layer, the water column is well-mixed with a temperature of approximately 19°C. Below the layer, temperature declined gradually to approximately 14°C. A similar pattern can also be seen in the density and salinity profiles recorded at this site, but to a smaller extent so that they appear almost uniform throughout the water column. Density varied between 1025 kg/m^3 at the surface and 1027 kg/m^3 at the seafloor and salinity between 35 PSU and 35.5 PSU, respectively. Also notable at H2 was the data spike at approximately 20 m below the surface in the profiles recorded on Survey 4 (April 25 2010). At that depth, temperature and density increased, and salinity decreased. This spike was not present on the other surveys. It is possible that the spike indicates the residual presence of the plume, but more likely it can be discounted as spurious.

The well-mixed layer was consistent on all survey days and at all sites profiled (Figures 3.12-3.17) though the thickness varied from day to day. Between April 10 and 15, the surface layer increased in thickness from 70 to 80 m but the temperature (~19.9°C) was consistent between days (Figures 3.12; 3.13; 3.15; 3.17). Between April 15 and 21, the thickness of the layer decreased significantly from 80 m to 30 m accompanied by a decrease in temperature to ~19.5°C (Figures 3.12; 3.13; 3.16; 3.17). By April 25, the layer had again increased to 80 m, but the temperature was stationary at ~19.5°C (Figures 3.12; 3.13; 3.14; 3.16). Similar to Site H2, density and salinity profiles mirror temperature patterns at the other sites, though to a lesser extent.

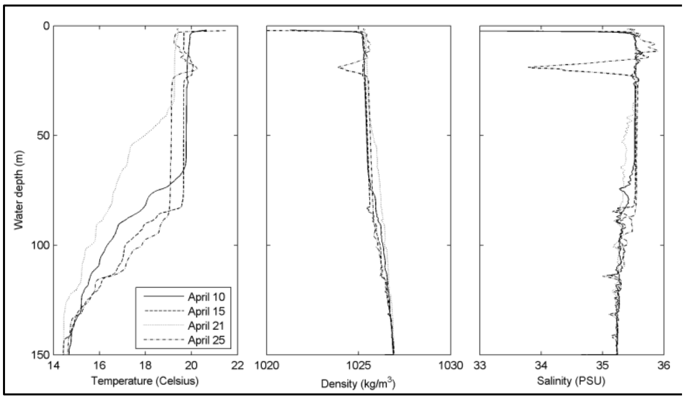


Figure 3.12 Temperature, density and salinity profiles at the centre (H2) of the disposal site (location for disposal) on April 10, 15, 21, & 25 (Surveys 1-4). Data collected using a "SeaBird" CTD.

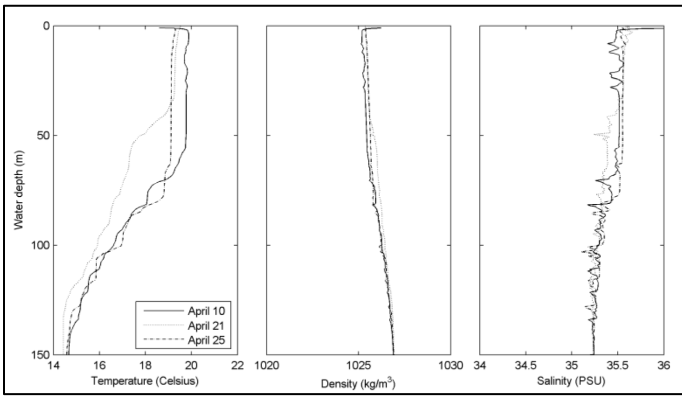


Figure 3.13 Temperature, density and salinity profiles at site I2 on April 10, 21, & 25 (Surveys 1,3 &4). Data collected using a "SeaBird" CTD.

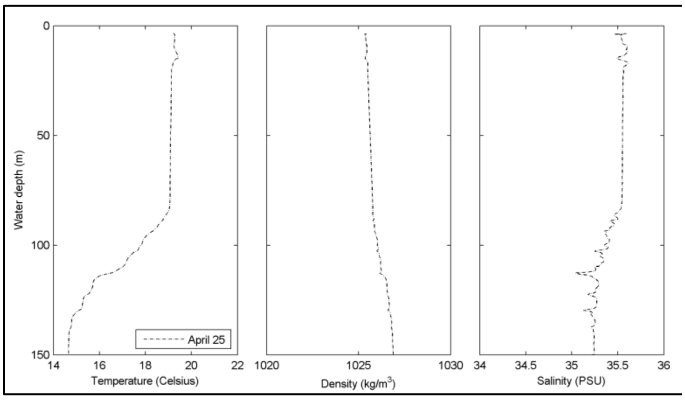


Figure 3.14 Temperature, density and salinity profiles at site G2 on April 25 (Survey 4). Data collected using a "SeaBird" CTD.

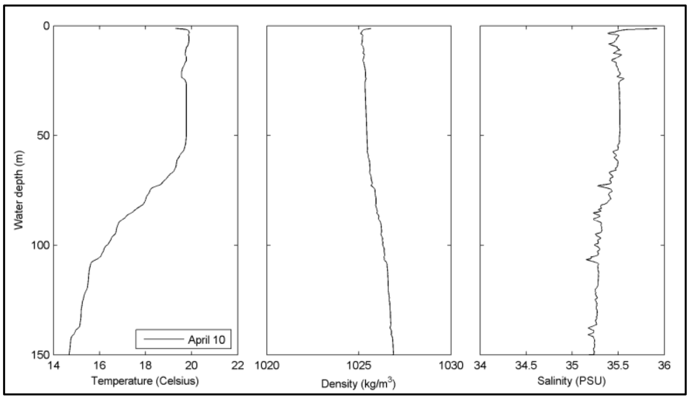


Figure 3.15 Temperature, density and salinity profiles at site H1 on April 10 (Survey 1). Data collected using a "SeaBird" CTD.

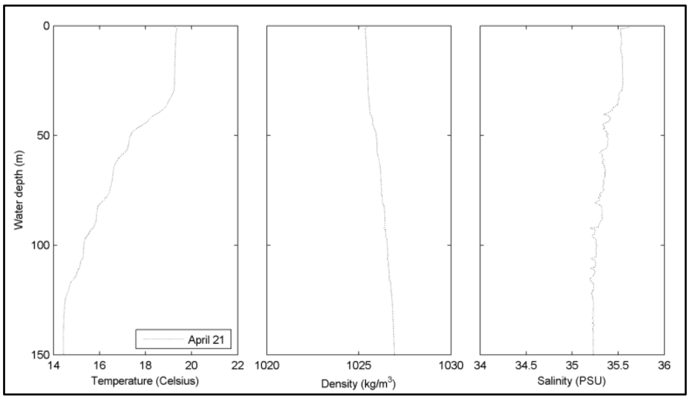


Figure 3.16 Temperature, density and salinity profiles 250 m east of the centre of the disposal site (H2/I2) on April 21. Data collected using a "SeaBird" CTD.

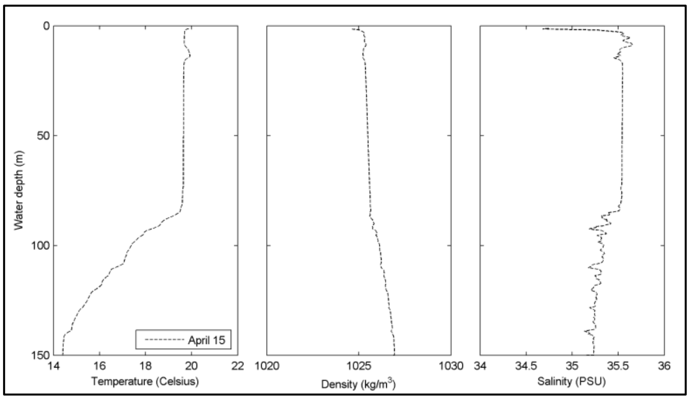


Figure 3.17 Temperature, density and salinity profiles at site I1 on April 15 (Survey 2). Data collected using a "SeaBird" CTD.

For seasonal comparison, representative CTD profiles recorded at the site in March, June, September and November are shown in Figure 3.18. The April 2010 patterns discussed above are largely the same as the "March" profile below. Temperature, density, and salinity ranges are very similar to those of the April 2010 ranges. The well-mixed top layer persists to a depth of approximately 60 m. The top layer of the March profile appears to be more strongly developed than those of the April 2010 survey profiles with a more precipitous jump to values of the lower layer. In September and November, the stratification appears non-existent with linear decreases in temperature from surface to seafloor. The June profile shows some evidence of stratification at approximately 120 m though it is not strongly developed in this example (Figure 3.18).

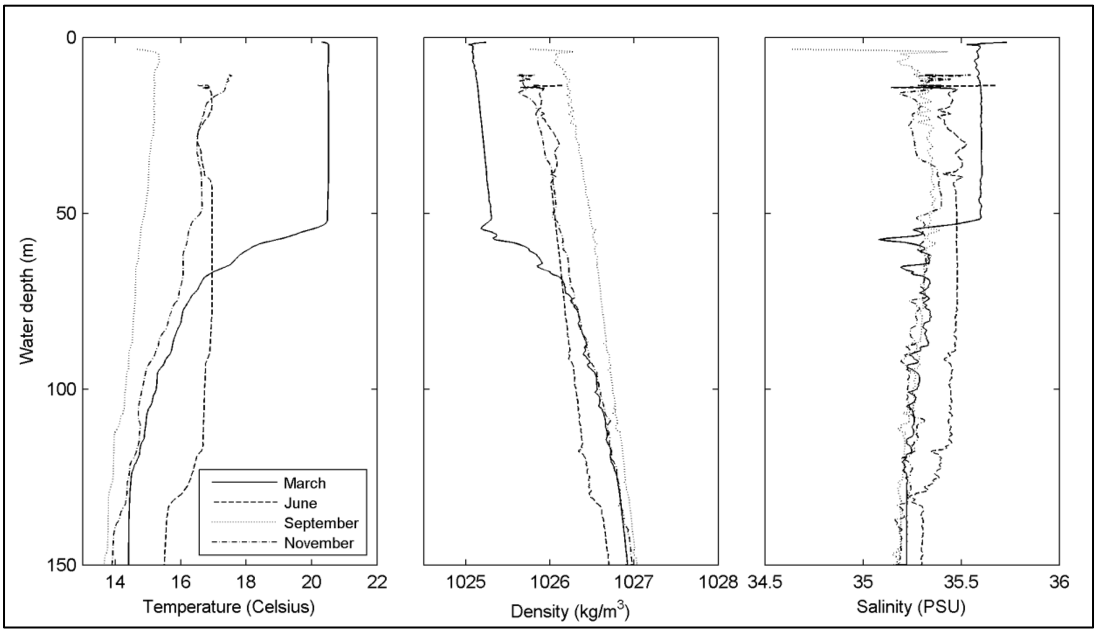


Figure 3.18 Representative temperature, density and salinity profiles near the centre of the disposal site for March, June, September, and November for comparison to April survey profiles. Data was collected using the same "SeaBird" CTD that was used in the plume monitoring surveys.

3.3.2 Drogues (Drifters)

The paths of each drifter deployed during each survey prior to arrival of the towed hopper are plotted in Figures 3.19 – 3.22. Generally, the drifters travelled on straight trajectories with only small deviations. However, the deep water drifters (30 m) deployed during Survey 1 are an exception (Figure 3.19). It appears that both drifters travelled on very indirect paths, but ended up in very similar positions to those of the shallow-water drifters (10 m).

Table 3.7 includes details of the drifter deployments in during each survey. The average speeds of the deep-water drifters in Survey 1, figured based on a straight trajectory, were 0.2 and 0.1 m/s. Those of the shallow water drifters in Survey 1 were 0.125 and 0.124 m/s. Despite the variability between the paths of the deep and shallow water drifters, the direction of the eventual trajectory of all four drifters was NNW of the deployment location (H2).

During Survey 2, the trajectories of the two drifters were virtually identical and directed toward the northeast (Figure 3.20). The shallow-water drifter travelled at a slightly higher speed that the deep-water drifter, at 0.19 and 0.16 m/s, respectively. In the case of Survey 3, both the deep and shallow water drifters travelled at 0.08 m/s towards the south (southeast) (Figure 3.21). At even lower speeds on Survey 4, both drifters travelled towards the west at only 0.03 m/s (Figure 3.22).

Based on a visual assessment of the drifter trajectories on each survey day, Stations A and B were positioned in the expected path of the disposal plume (Figure 3.7). Station C was positioned on the opposite side where turbidity levels were expected to remain at background "ambient" levels (Figure 3.7).

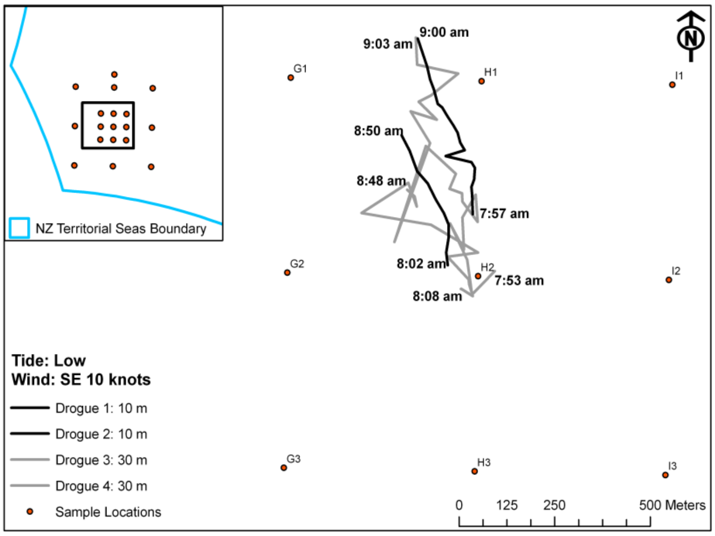


Figure 3.19 Path of drogues 1 & 2 (10 m below surface) (black) and drogues 3 & 4 (30 m below surface) (gray) on April 10 (Survey 1). First and last GPS transmit times as well as tide and wind conditions are noted.

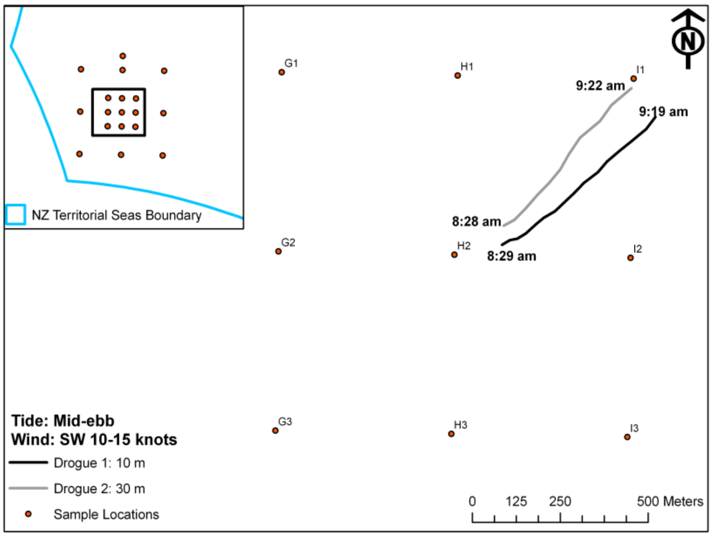


Figure 3.20 Path of drogues 1 (black) & 2 (gray) (10 m and 30m below surface, respectively) on April 15 (Survey 2). First and last GPS transmit times as well as tide and wind conditions are noted.

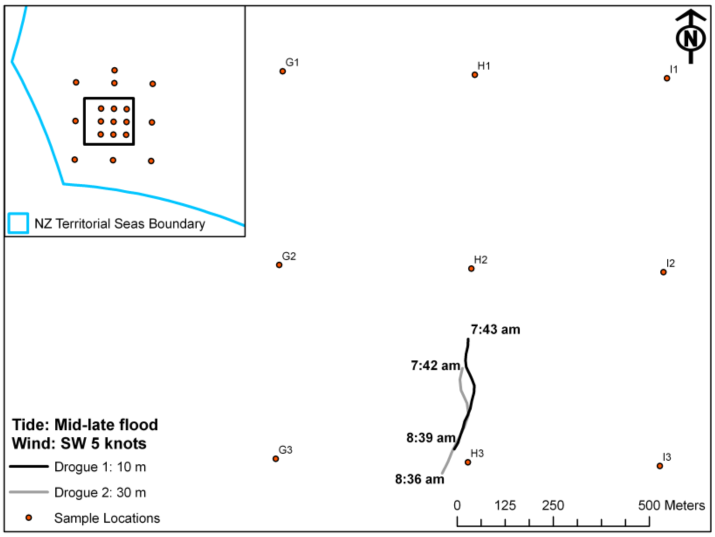


Figure 3.21 Path of drogues 1 (black) & 2 (gray) (10 m and 30m below surface, respectively) on April 21 (Survey 3). First and last GPS transmit times as well as tide and wind conditions are noted.

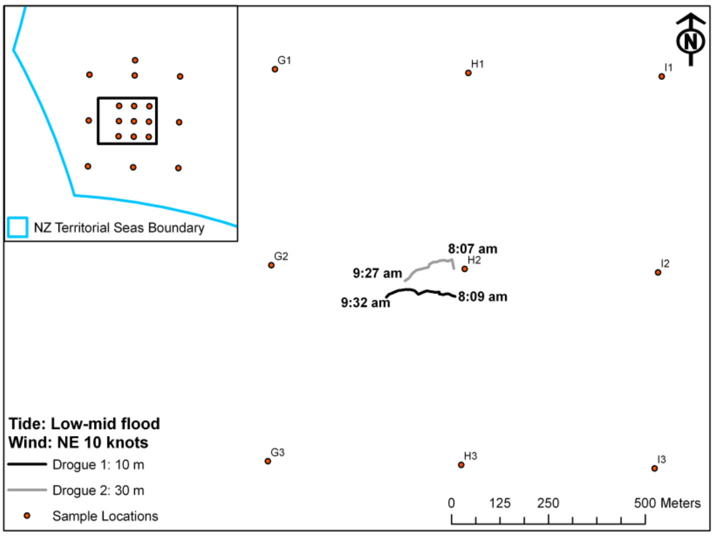


Figure 3.22 Path of drogues 1 (black) & 2 (gray) (10 m and 30m below surface, respectively) on April 25 (Survey 4). First and last GPS transmit times as well as tide and wind conditions are noted.

Table 3.7 Details of drifter deployment on April 10, 15, 21, and 25 2010 (Surveys 1-4, respectively).

Survey	Drifter No.	Drifter depth (m)	Net distance (m)	Time (s)	Average speed (m/s)	Direction
1	1	10	473	3780	0.125	NNW
	2	10	358	2880	0.124	NNW
	3	30	665	3300	0.2	NNW
	4	30	332	3300	0.1	NNW
2	1	10	561	3000	0.19	NE
	2	30	517	3240	0.16	NE
3	1	10	274	3360	0.08	SSW
	2	30	267	3240	0.08	SSW
4	1	10	188	4980	0.03	W
	2	30	143	4800	0.03	W

3.3.3 Water Sample and Turbidity Sensor Data

Suspended sediment concentration (mg/L) (SSC) was measured from water sample data and estimated from scaled turbidity sensor data collected conjointly at each of the survey stations during the plume monitoring surveys. For that reason, the two data sets for each survey will be presented together in this section. As described above, Stations A and B were positioned with the objective of recording plume conditions and Station C was positioned to record ambient conditions. In fact, it was observed in Surveys 1 and 2 that often even though Stations A and B were in the trajectory of the plume, they were positioned too far from the release location. Often this meant that the data recorded in those positions was along the edge of the plume where turbidity levels were almost indistinguishable from background levels. Part way through Survey 2, an attempt was made to record from within the plume by relocating Stations A and B, which unfortunately did not have the desired effect due to equipment problems. Having learned lessons from Surveys 1 and 2, Stations A and B were positioned more effectively in Surveys 3 and 4. In these instances, Station A was positioned at the release location after the hopper was towed out of the way. Station B was positioned in the expected trajectory of the plume, but somewhat closer to the release location than in previous surveys.

Despite not having sampled the plume explicitly from Stations A and B in Surveys 1 and 2, information related to the spatial extent can still be gathered. In this way, determining where the plume did *not* disperse can be as useful (especially in conjunction with other monitoring data) as determining in what areas the plume did disperse. In Surveys 3 and 4 the positioning of Stations A and B gave information on the one hand, related to the degradation of the plume at the release location and on the other hand, its stability as it dispersed away from the release location.

Table 3.8 lists the suspended sediment concentration (mg/L) of each water sample collected in sequence during each survey. Figures 3.23-3.26 shows the time series of water sample SSC superimposed with sensor estimated SSC time series from respective stations and depths. During Survey 1, water sample data and sensor data collected at Stations A and B were similar to that collected at Station C (similarly low turbidity levels were recorded at Station D, which was also positioned as an “ambient” station (Figure 3.23). Water sample SSC fluctuated similarly at all three stations and sensor data was reasonably similar to water sample data considering potential inaccuracies in scaling.

Table 3.8 Suspended sediment concentration (SSC) (mg/L) of water samples collected at Stations A, B, & C on April 10, 15, 21, & 25 (Surveys 1-4).

Station	Date	Time	5 m*	10 m*	Date	Time	5 m*	10 m*	Date	Time	5 m*	10 m*	Date	Time	5 m*	10 m*
A	10-Apr-10	11:00	3.30	3.00	15-Apr-10	9:55	15.30	8.48	21-Apr-10	9:57	-	-	25-Apr-10	10:25	-	-
		11:05	-1.80	2.14		10:00	1.26	6.30		10:02	-	-		10:30	-	-
		11:10	1.40	0.70		10:05	1.20	10.60		10:07	10.80	12.90		10:35	15.90	15.90
		11:15	0.70	0.10		10:10	6.70	9.20		10:12	28.20	30.20		10:40	3.80	10.80
		11:20	0.60	0.20		10:15	5.60	2.60		10:17	11.30	3.10		10:45	0.60	4.60
		11:25	1.60	0.50		10:20	8.30	3.70		10:22	4.40	3.70		10:50	11.60	2.40
		11:30	0.50	-		10:25	15.10	-		10:27	4.90	7.20		10:55	3.50	1.30
		11:35	3.30	0.90		10:30	3.90	16.10		10:32	7.20	5.60		11:00	10.00	3.30
		11:40	0.70	2.00		10:35	19.70	3.70		10:37	3.70	3.30		11:05	9.60	6.10
		11:45	3.90	4.20		10:40	-	7.10		10:42	6.70	1.90		11:10	5.70	10.80
		11:50	1.60	2.50		10:45	4.80	3.90		10:47	1.50	25.50		11:15	11.50	7.60
		11:55	-	-		10:50	10.60	10.20		10:52	-0.10	1.00		11:20	6.30	21.20
		-	-	-		10:55	6.70	7.50		10:57	2.70	11.40		11:25	16.10	11.20
		-	-	-		11:00	-	-		11:02	2.70	1.40		11:30	8.60	7.20
		-	-	-		11:05	-	-		11:07	1.30	4.00		11:35	5.30	12.30
		-	-	-		11:10	-	-		11:12	5.00	2.70		11:40	12.90	6.60
		-	-	-		11:15	29.60	7.60		11:17	3.10	8.40		-	-	-
		-	-	-		11:20	23.00	8.40		-	-	-		-	-	-
		-	-	-		11:25	4.60	4.50		-	-	-		-	-	-
B		11:00	2.60	6.80		9:55	20.71	17.20		9:57	4.80	6.10		10:25	11.07	7.50
		11:05	1.00	2.50		10:00	11.70	6.00		10:02	15.00	6.10		10:30	5.79	13.00
		11:10	-0.60	3.40		10:05	7.10	4.80		10:07	2.35	1.30		10:35	4.90	6.20
		11:15	0.80	12.10		10:10	11.00	11.70		10:12	1.10	3.50		10:40	4.02	7.00
		11:20	3.70	2.40		10:15	5.90	2.20		10:17	4.77	2.20		10:45	10.26	5.60
		11:25	2.04	1.10		10:20	5.80	4.80		10:22	10.67	30.90		10:50	7.90	7.40
		11:30	3.94	1.30		10:25	7.40	10.00		10:27	1.39	4.90		10:55	6.63	8.30

	11:35	2.60	1.30		10:30	2.40	4.10		10:32	2.38	1.30		11:00	5.16	7.20
	11:40	2.00	2.90		10:35	3.40	2.60		10:37	11.73	14.80		11:05	8.22	7.30
	11:45	1.80	3.90		10:40	2.10	4.30		10:42	1.99	4.60		11:10	12.95	8.80
	11:50	3.60	1.90		10:45	4.90	4.90		10:47	12.32	0.60		11:15	18.24	17.40
	11:55	1.90	2.70		10:50	11.60	5.30		10:52	2.96	1.60		11:20	23.08	15.10
	-	-	-		10:55	3.50	5.90		10:57	2.37	2.60		11:25	11.17	4.70
	-	-	-		11:00	-	-		11:02	1.34	1.60		11:30	16.26	8.20
	-	-	-		11:05	-	-		11:07	1.08	4.40		11:35	7.08	4.40
	-	-	-		11:10	2.40	8.20		11:12	23.08	7.30		11:40	16.65	5.20
	-	-	-		11:15	3.40	3.80		11:17	15.94	22.20		-	-	-
	-	-	-		11:20	-	-		-	-	-		-	-	-
C	11:00	0.95	10.32		8:30	24.09	10.33		9:57	6.07	1.44		10:25	11.15	7.59
	11:05	6.97	17.58		8:35	20.64	26.59		10:02	4.79	9.79		10:30	11.61	8.47
	11:10	6.47	3.06		8:40	3.00	55.90		10:07	4.70	7.55		10:35	8.20	4.61
	11:15	9.35	6.32		8:45	14.58	7.31		10:12	1.28	0.82		10:40	5.37	2.75
	11:20	5.95	8.85		8:50	21.54	16.20		10:17	5.00	2.74		10:45	4.56	14.18
	11:25	6.43	25.21		8:55	2.50	6.30		10:22	1.16	6.12		10:50	4.44	14.00
	11:30	11.71	20.00		9:00	3.24	9.65		10:27	3.24	2.20		10:55	19.36	22.61
	11:35	7.24	7.01		9:05	7.78	26.97		10:32	1.96	2.86		11:00	25.83	7.30
	11:40	58.00	52.43		9:10	27.10	15.94		10:37	2.01	4.86		11:05	5.24	14.78
	11:45	33.64	7.03		-	-	-		10:42	5.54	2.37		11:10	10.24	4.54
	11:50	76.69	13.49		-	-	-		10:47	4.95	3.19		11:15	4.47	31.81
	11:55	11.96	11.50		-	-	-		10:52	1.09	1.10		11:20	30.05	26.56
	-	-	-		-	-	-		10:57	2.13	2.58		11:25	3.93	3.68
	-	-	-		-	-	-		11:02	3.39	4.80		11:30	9.17	2.61
	-	-	-		-	-	-		11:07	2.70	3.78		11:35	5.63	-
	-	-	-		-	-	-		11:12	2.90	5.58		-	-	-
	-	-	-		-	-	-		11:17	7.85	6.48		-	-	-

*values are in mg/l

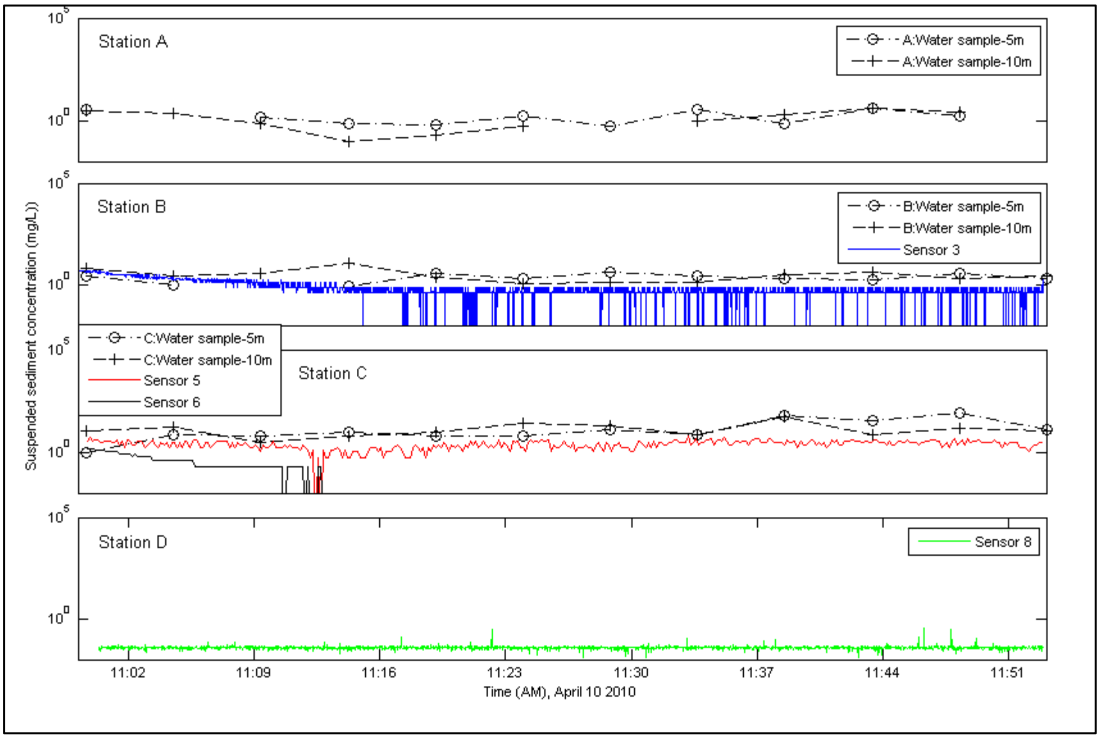


Figure 3.23 Turbidity sensor data (scaled to SSC (mg/L)) and water sample data (mg/L) collected at Stations A, B, C, & D on April 10 2010 (Survey 1).

During Survey 2, turbidity levels at Station C were very similar to those determined at Station C during Survey 1 (Figure 3.24). Again at Stations A and B in Survey 2, turbidity levels before relocation were similar to those at Station C. There appears to be some fluctuation recorded at Station A by Sensor 8 but the increases are short-lived and not much above background levels. After relocation to Stations A2 and B2, there was a slight increase in turbidity levels picked up in both the water sample data as well as the sensor data for the short period before equipment failure. This was especially noticeable in data recorded by Sensor 8 at Station A.

During Surveys 3 and 4, data recorded at Station C mirrored that of the first two surveys and similar to Surveys 1 and 2, Station B appears to have not picked up the plume as obviously as what would have been expect based on positioning used in the last two surveys (Figures 3.25 and 3.26). Data from Station B is similar to that of Station C, with no large increases in turbidity beyond background levels. Patterns differed slightly in Station A for Surveys 3 and 4 however. In Survey 3, turbidity levels at the beginning of the survey are substantially higher than at the end of the survey. This pattern was mainly identified in the data records of Sensors 8 (10 m) and 9 (7 m) though to a lesser extent the water samples appear to have had higher SSC towards the beginning of the survey compared to end as well (Figure 3.25). Approximately 20 min after the start of the survey, turbidity levels recorded by Sensors 8 and 9 dropped off to background levels for the remainder of the survey (Figure 3.25). In Survey 4, Sensor 9, this time deployed at 5 m, recorded similar high turbidity levels at the beginning of the survey which dropped off after approximately 20 min (Figure 3.26). However, this time, Sensor 8, deployed at 10 m, did not reflect the increase in turbidity levels until approximately 30 min after the release of dredged material. The increased levels recorded by Sensor 8 lasted for approximately 30 min, at which point levels decreased to background for the remainder of the survey.

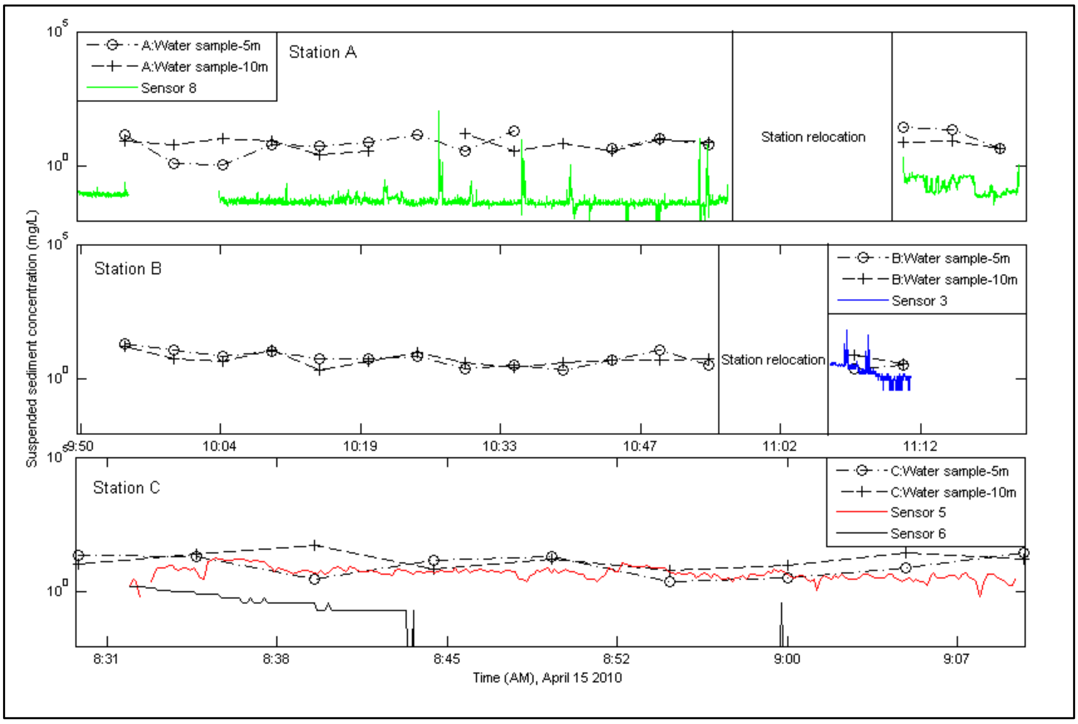


Figure 3.24 Turbidity sensor data (scaled to SSC (mg/L)) and water sample data (mg/L) collected at Stations A, B & C on April 15 2010 (Survey 2).

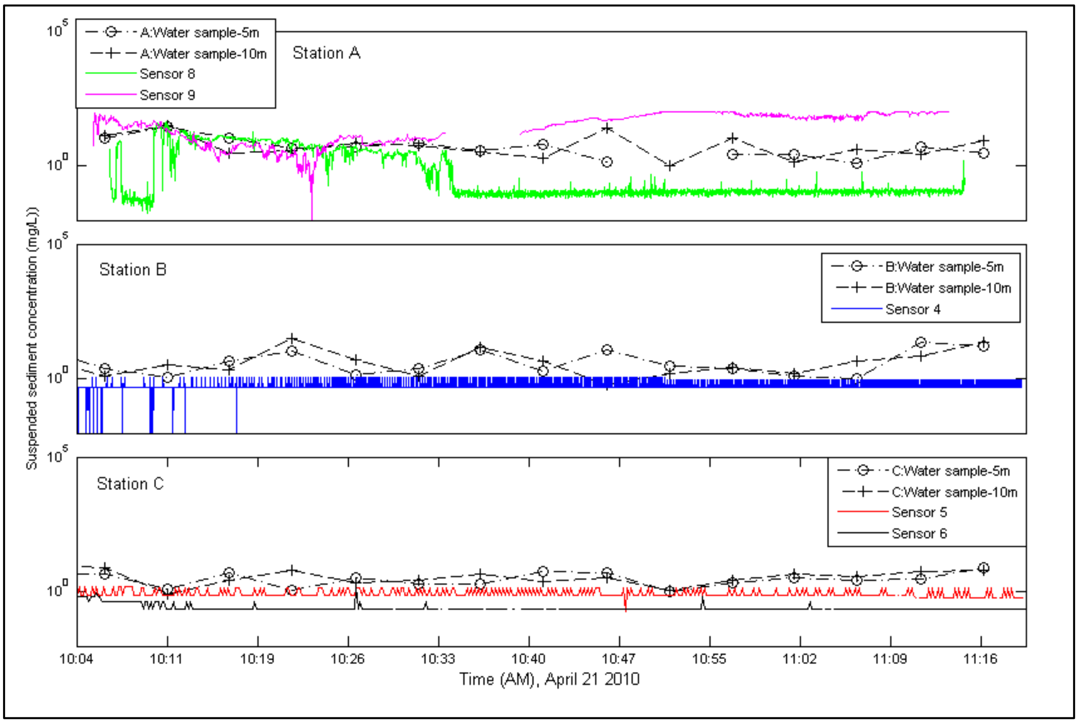


Figure 3.25 Turbidity sensor data (scaled to SSC (mg/L)) and water sample data (mg/L) collected at Stations A, B & C on April 21 2010 (Survey 3).

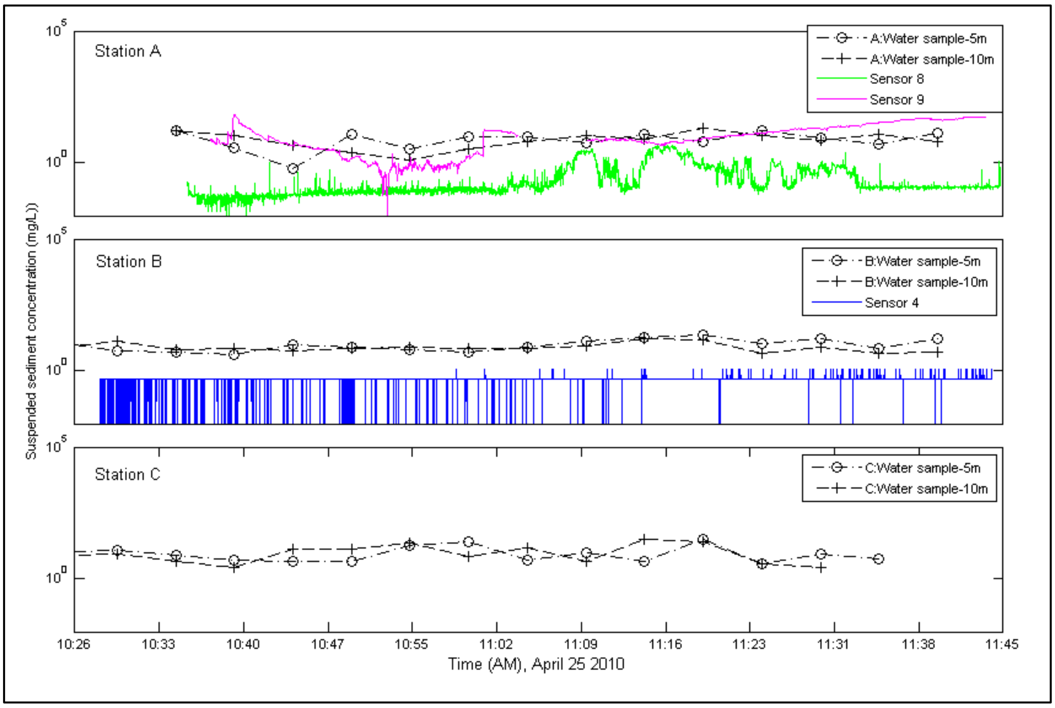


Figure 3.26 Turbidity sensor data (scaled to SSC (mg/L)) and water sample data (mg/L) collected at Stations A, B & C on April 25 2010 (Survey 4).

3.3.4 BIO-FISH Turbidity Sensor Data

To simplify the BIO-FISH operational procedure, transmission data were recorded as one file starting after the release of dredged material and ending when the plume was nearly indistinguishable from ambient water (~1 hour after disposal). For analysis, BIO-FISH data were split into individual transects matching those recorded using the ADCP (Table 3.6). However, transects 1 and 1-5 of Surveys 3 and 4, respectively, were not recorded by the BIO-FISH owing to some initial deployment issues.

Figure 3.27 shows the full data record of percent transmission for the length of each BIO-FISH survey including a top view of the individual transect locations (colour represents the transect sequence). On both surveys, recurring decreases in transmission were recorded for the length of the survey as the vessel passed in and out of the plume. Generally, the difference between background turbidity and plume levels diminished with time, with the exception of one outlier record towards the end of Survey 3 where transmission was recorded at almost 0 % (likely due to seaweed floating through the beam). Background levels during Survey 3 were approximately 90% transmission indicating close to 100% transparency. The largest decrease in transparency (i.e. increase in turbidity) was recorded at the beginning of the survey (~12 min post-disposal) in Transect 4 where transparency dipped to 35%. At the end of the same survey, during Transect 17 (~65 min. post disposal), the minimum transparency was 75 %. As Transect 17 was comparatively long (~15 min), a further increase in transparency to background levels was recorded at the end of the transect (~75 min post disposal). Background levels recorded during Survey 4 ranged from 80-85% transmission. The lowest transparency was recorded in Transect 7 (~20 min post-disposal) where transmission decreased to 57%. The lowest transmission recorded during the last transect of Survey 4 (Transect 17, ~65 min post-disposal) was 70%.

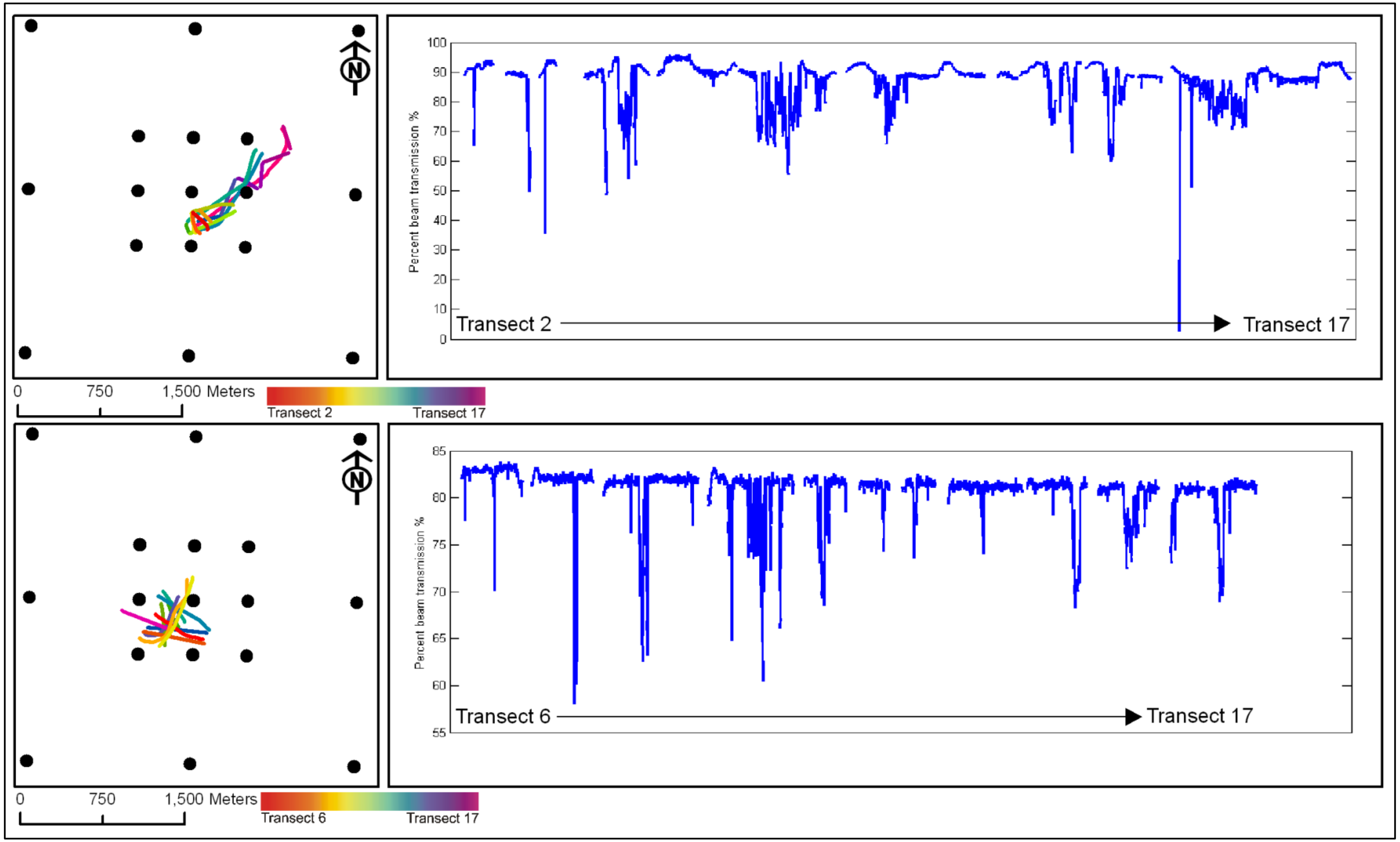


Figure 3.27 On left: top view of BIO-FISH transects (top: Survey 3) and (bottom: Survey 4). On right: Percent beam transmission time series recorded by the BIO-FISH transmissometer sensor during (top: Survey 3 - transects 2-17) and (bottom: Survey 4 - transects 6-17).

3.3.5 ADCP Backscatter Data

ADCP backscatter data recorded during each of the four plume monitoring surveys provided valuable insight into the characteristics of the resultant plume after each monitored disposal event. For the purpose of describing fate and dispersal characteristics observed from the ADCP backscatter data, the following terms will be used:

Background levels-refers to the ADCP backscatter level recorded when not in the presence of the disposed material; reflects naturally occurring suspended particles in the water column.

Ensemble-one set of vertical backscatter data that appears as a “column” of colour assigned data in the plots; each ensemble is comprised of one set of GPS coordinates and the respective vertical backscatter data; each ensemble is averaged from 8 rapidly transmitted pings (acoustic pulses).

Main component-the densest portion of the disposed material (made up of the clumps or blocks of dredged material) which descends almost as one unit rapidly to the seafloor; the descent of this portion is often described as a “jet” of material because of the speed with which it falls (Figure 3.28).

Entrained component-described as the portion of material entrained or mixed into the water column; typically occurs along the outside of the descending jet of material; can arise anywhere along the length of the jet and can increase in concentration at the seabed as a result of impact energy which causes mixing with and further entrainment of native sediments (Figure 3.28).

Dispersed component- any material which, following initial entrainment from the descending jet into the surrounding water column, is dispersed away from its initial location by local currents (Figure 3.28).

Hopper washout-fine material washed out of the hopper in the few seconds after the main component of the dredged material has exited the hopper and prior to the closing of the doors; since the hopper was towed west to east and did not stop during release, the washout appeared as a trail behind the hopper east of the release location.

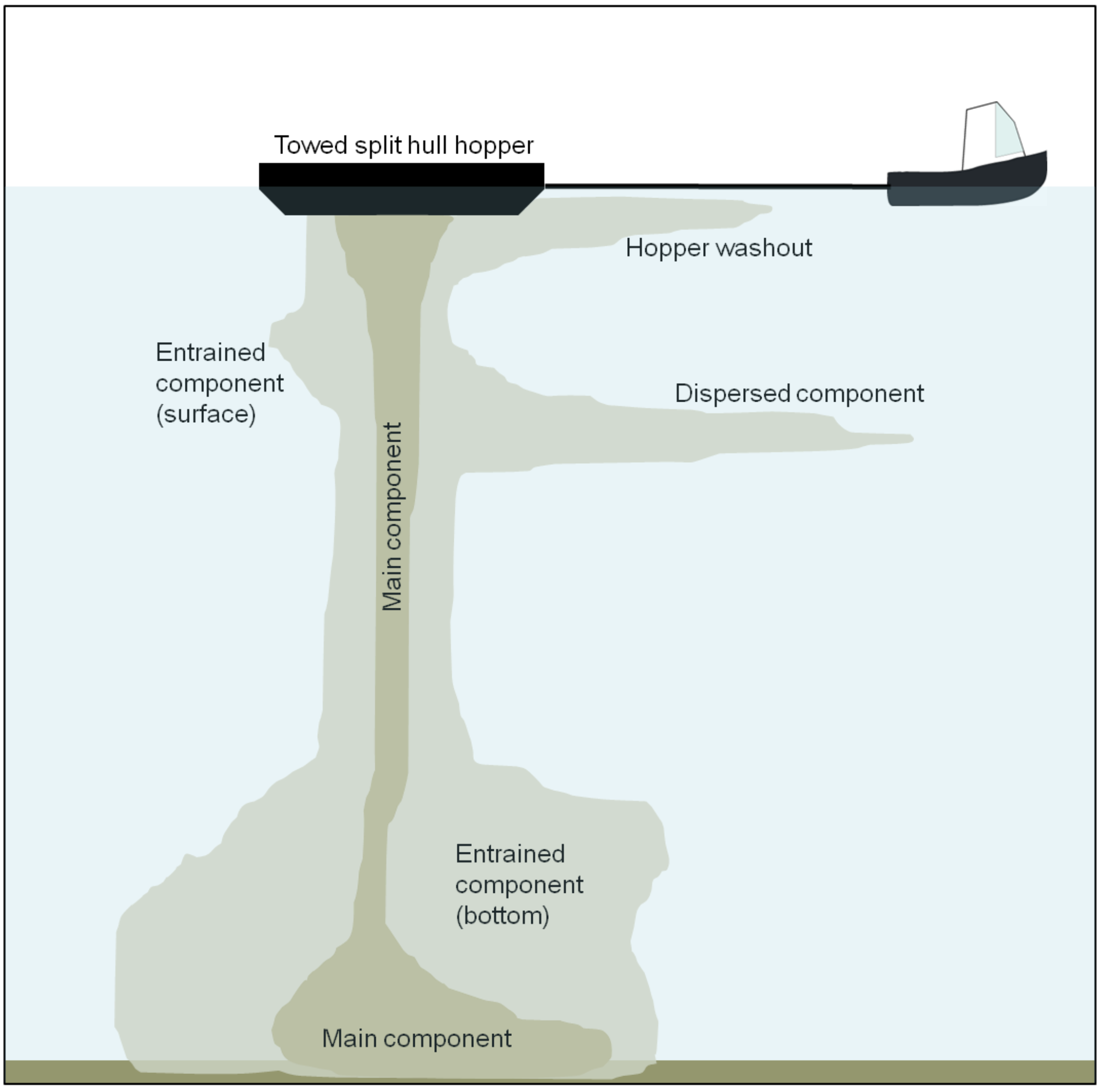


Figure 3.28 Diagram of time-averaged components of dredged material released in open water as it descends through the water column to the seafloor (not to scale).

The following sections include figures depicting ADCP backscatter data from each survey. Each figure shows at least two transects from the survey. Transects not included in the figures either were of bad quality, did not show the plume or were redundant. In a general manner, the transects are displayed sequentially to give an impression of the spatial extent of the plume at that moment (e.g. Figure 3.29). The exact times of each transect are listed in Table 3.6, but transect numbering is chronological for simplicity. Occasionally, transects recorded early in the survey are plotted against transects recorded later in the survey, especially if they were recorded in similar locations (e.g. Figure 3.36; Transects 18 and 24 of Survey 1 recorded ~15 min apart). This gives the effect of time lapse and how the turbidity changed at that location through time. Each figure includes three views of the ADCP backscatter data: (A) is the top-view which shows the location of each transect with respect the release location (H2), (B) is the geo-referenced 3-dimensional view of the vertical ADCP backscatter along both transects and (C) is the 2-dimensional view of ADCP backscatter transects side by side for comparison. Each figure also includes a legend showing the backscatter level in decibels (dB) and its representative colour used in the plots. In basic terms, higher dB levels (hotter colours) represent higher intensity backscatter returns which can be inferred as either areas of higher concentrations of suspended particles or areas of larger suspended particles. In this case, it is assumed that the hot coloured areas represent the disposal plume.

Survey 1

Observations of the disposal plume characteristics based on ADCP backscatter data are tabulated in Table 3.9. Figures 3.29 – 3.37 show ADCP backscatter data recorded during the first plume monitoring survey on April 10 2010. The following summarises the main observations from ADCP backscatter data recorded in Survey 1:

i. Initially, the main component of the disposed material descended rapidly and landed 200-250 m north of H2;

ii. Material entrained at the seafloor immediately following impact of the main component remained approximately 250 m north of H2 for the length of the survey (this suspension had a diameter of at least 150-200 m and decreased in density/concentration significantly by the end of the survey);

iii. The entrained component near the surface dispersed northward. Initially, this dispersed component had a width of 200 m east to west and a length of 200 m north to south (including the trail of descending material leading back to point of impact at the seafloor);

iv. Eventually, the dispersing surface component detached from bottom entrained material still sitting in the area of impact and drifted to a maximum of ~600 m north of H2, while undergoing further dilution and settling;

v. After 50 min, the dispersing surface component was only just above background levels;

vi. It is estimated that the majority of the disposed material settled within 500 m north of H2.

Table 3.9Post-disposal plume characteristics observed from ADCP backscatter data recorded during Survey 1.

Survey 1: April 10 2010							
Transect	**Figure No.**	**Post-disposal time (min)**	**Location in water column**	**Geographic location (from H2)***	**Component**	**Dimensions***	**Comments**
4	3.27	Before	n/a	n/a	n/a	n/a	"background" levels
5	3.27	0-5	Throughout	250 m NW	Main & entrained	200 m SW-NE	Blank ensembles indicate blocked data; represents very high density main component during descent
7	3.28	5	Throughout (densest near surface)	300 m N	entrained	150-200 m W-E	Entrained fines immediately after descent of main component; not yet dispersed from release location
10	3.28-3.30	10-15	Throughout; densest at mid-column; widest at bottom	300-400 m NNE	dispersed	200 m Surface to bottom (N-S)	At intersection with T7, surface component has shifted 75 m north, but the densest component has descended from the surface to mid-column depths compared to T7
11	3.29	15	Mid-lower	250-400m NNW	Main/bottom entrained	150-200 m SE-NW	Entrained/settling component at bottom; no surface component; no dispersion towards the NW
12	3.30 & 3.31	15-20	Surface to mid	500 m N	dispersed	200 m E-W	At intersection with T10, surface component has shifted 50 m north; lower column component has remained closer to H2
15	3.32	25	Mid-lower	300-450 m	Main/bottom	150-200 m	Compared to T11, suspended material has similar

				NNW	entrained	SE-NW	dimensions and lower density which implies settling, but not dispersion
16	3.31	25-30	Surface-mid	500-600 m N	dispersed	300 m Surface to bottom (NE-SW)	At intersection with T12, surface component has shifted 200 m north; low density surface component with higher density mid-depth component indicates settling
17	3.33 & 3.33	30-35	Surface-lower	See T16	See T16	See T16	5 min after T16, dimensions of dispersed component are unchanged, but an increase in density close to the bottom indicates further settling
18	3.34	35	Mid-lower	400 m N	Main/bottom entrained	At least 150 m SW-NE	Edge of bottom entrained material in T15; lower in density and lower in water column indicates settling
22	3.33 & 3.35	45	Surface-lower	See T16	See T16	See T16	15 min after T17, dimensions of dispersed component are unchanged, but density has decreased to just above background levels
24	3.34 & 3.35	50	Surface & lower	400-500 m N	Surface dispersed & bottom entrained	Surface ~ 100 m Bottom ~ 400 m	Surface component shifted ~50 m north compared to T22; compared to T10 & T15, bottom component is significantly diminished in density (just above background).

*Measures are approximate

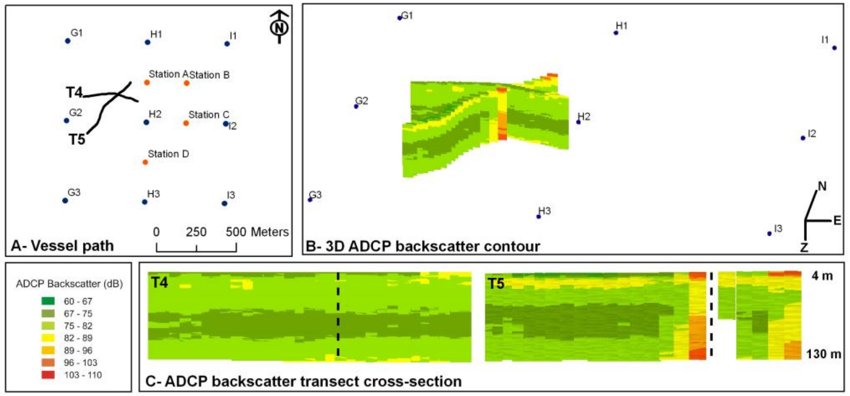


Figure 3.29 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 4 and 5 of Survey 1 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

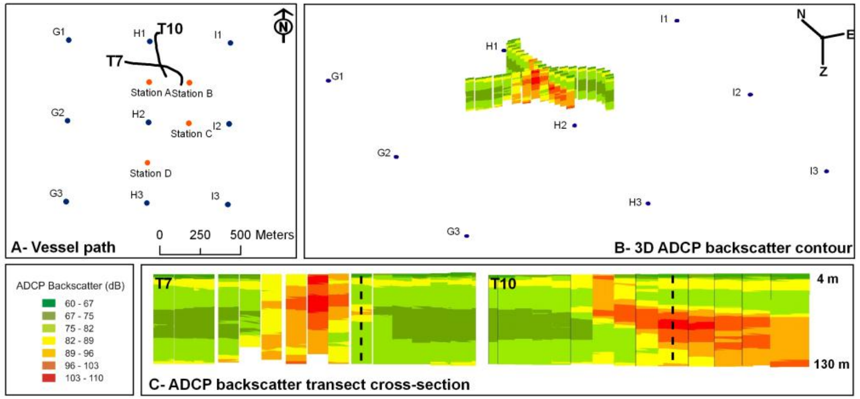


Figure 3.30 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 7 and 10 of Survey 1 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

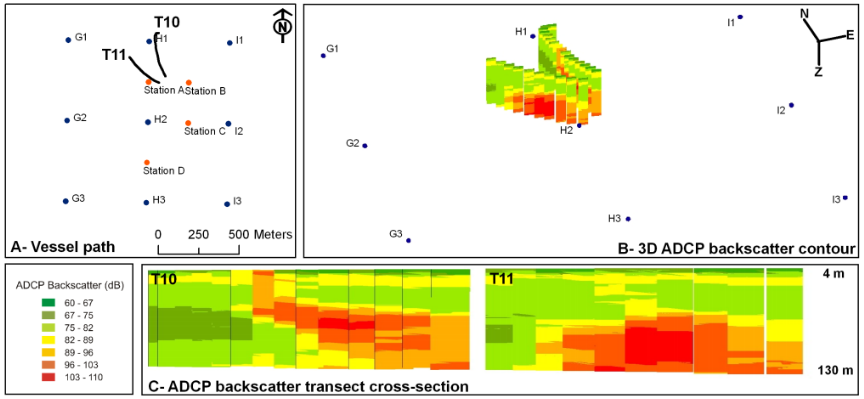


Figure 3.31 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 10 and 11 of Survey 1 collected by the vessel-mounted 250 kHz RDI ADCP.

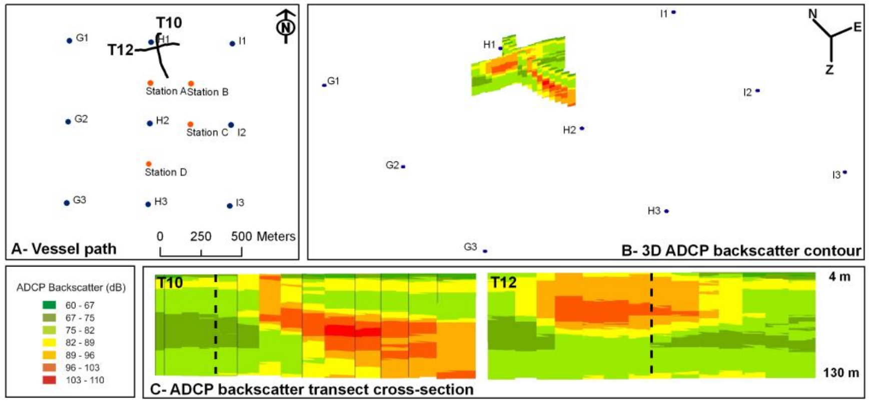


Figure 3.32 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 10 and 12 of Survey 1 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

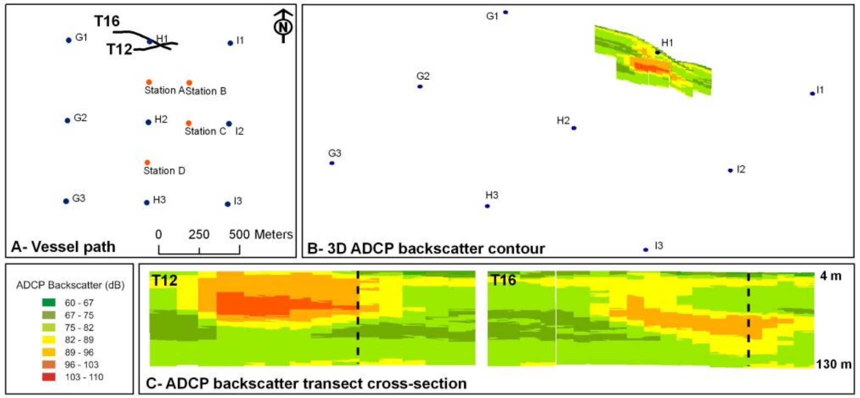


Figure 3.33 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 12 and 16 of Survey 1 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

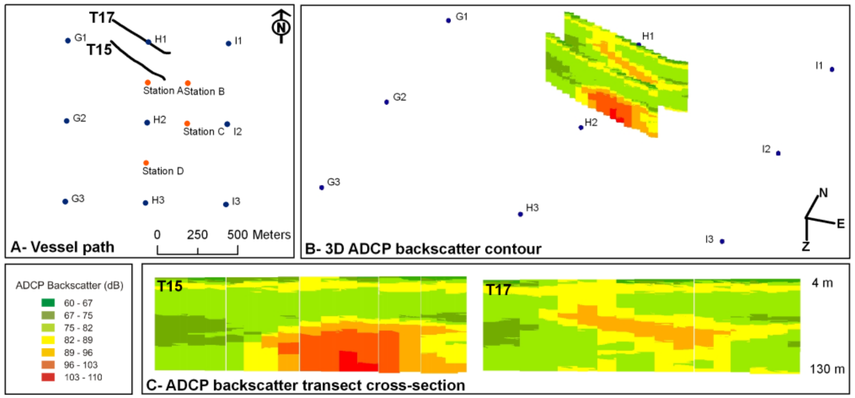


Figure 3.34 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 15 and 17 of Survey 1 collected by the vessel-mounted 250 kHz RDI ADCP.

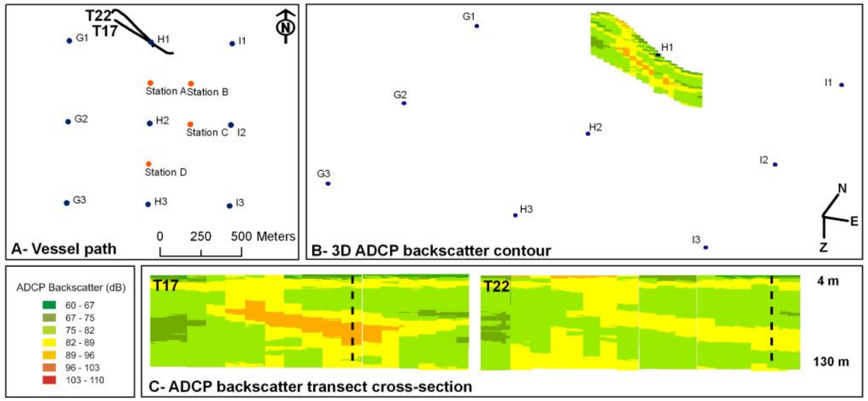


Figure 3.35 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 17 and 22 of Survey 1 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

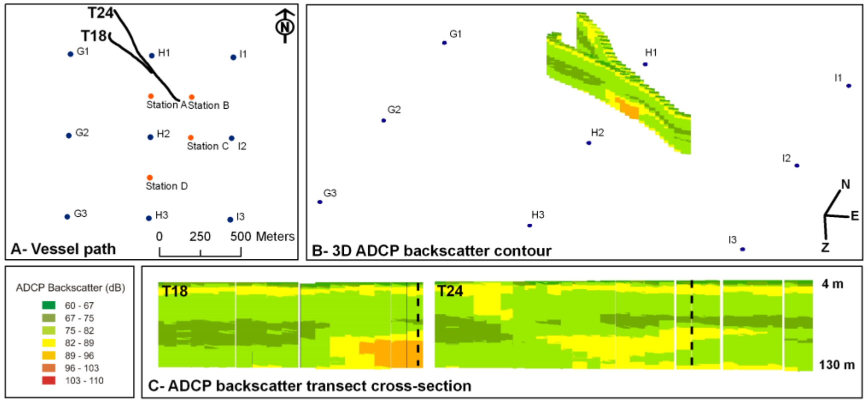


Figure 3.36 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 18 and 24 of Survey 1 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

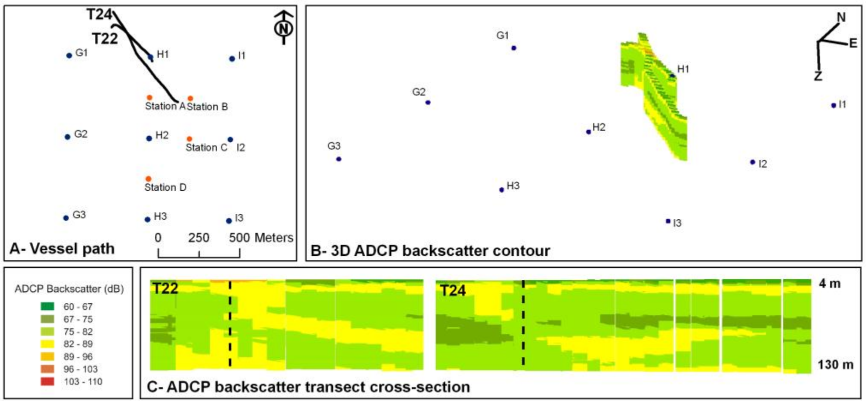


Figure 3.37 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 22 and 24 of Survey 1 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

Survey 2

Observations of the disposal plume characteristics based on ADCP backscatter data are tabulated in Table 3.10. Figures 3.38 – 3.47 show ADCP backscatter data recorded during the second plume monitoring survey on April 15 2010. The following summarises the main observations from ADCP backscatter data recorded in Survey 2:

i. In the period immediately following release, the main component of the disposed material landed approximately 250 m southeast of H2;

ii. 10-15 min after release, the surface component of the plume was detected in very dilute concentrations ~500 m east of H2;

iii. 20 minutes after release, the concentration of entrained material was highest 250 m east of H2 and closer to the seabed. Beyond ~300 m northeast of H2, there was no bottom component and the surface component became increasingly dilute;

iv. During the survey, the bottom component of the plume was not observed further than ~500 m northeast of H2. The surface component decreased to background levels ~750 m northeast of H2;

v. After 1 hour turbidity levels in the areas surveyed were approximately equal to background levels.

Table 3.10 Post-disposal plume characteristics observed from ADCP backscatter data recorded during Survey 2.

Survey 2: April 15 2010							
Transect	**Figure No.**	**Post-disposal time (min)**	**Location in water column**	**Geographic location (from H2)***	**Component**	**Dimensions***	**Comments**
1	3.36 & 3.37	0-5	Throughout	125m SE	Main & entrained	50-100 m SW-NE	Blank ensembles indicate blocked data; represents very high density main component during descent
2	3.36 & 3.38	0-5	Throughout	250-300 m E	Main & entrained	75 m W-E	Blank ensembles indicate blocked data; represents very high density main component during descent
5	3.39	10	Surface	500 m ENE	dispersed	25-50 m NW-SE	Cross-section of the width of fines dispersed eastward of the disposal location so soon after release are probably contributed to by hopper wash-out
6	3.39	10-15	Surface-Mid	300-400 m E	dispersed	25-50 m N-S	Similar to T5; most likely hopper wash out, depth of suspended material increases with proximity to release location
7	3.38	10-15	Throughout	250-300 m E	Entrained & dispersed	100 m NW-SW	Cross-section of the width of entrained material dispersed eastward; densest at mid-column depths
8	3.37 & 3.40	15	Throughout	200 m E	Entrained & dispersed	50-100 m NW-SE	Similar to T7, but 5 min later, the densest portion is closer to the seabed indicating rapid settling of the entrained component
9	3.40 & 3.41	15-20	Throughout	100-600 m NE	dispersed	500 m SW-NE	Cross-section of the length of eastwardly dispersed material; densest closer to H2 and closer to the seabed
12	3.41 & 3.42	25-30	Surface-mid	250-750 m NE	dispersed	500 m SW-NE	Similar to T9, 10-15 min later; significant decrease in turbidity especially at the surface indicating settling

14	3.42 & 3.43	35	Throughout	See T12	dispersed	See T12	10 min after T12, dimensions of dispersed component are unchanged, but turbidity continued to decrease with time
16	3.43 & 3.44	45	Surface-Mid	See T12	dispersed	See T12	10 min after T14, dimensions of dispersed component are unchanged, but turbidity continued to decrease with time
23	3.44 & 3.45	75	Surface	500 m NE	dispersed	n/a	More than an hour after disposal, turbidity levels are just above background at the surface, levels are not elevated elsewhere in the water column
26	3.45	80-85	Surface	600 m NE	dispersed	n/a	More than an hour after disposal, turbidity levels are just above background at the surface, levels are not elevated elsewhere in the water column

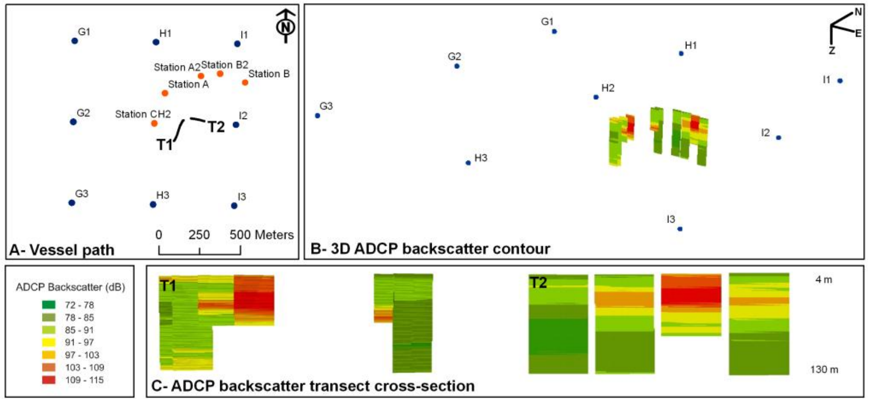


Figure 3.38 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 1 and 2 of Survey 2 collected by the vessel-mounted 250 kHz RDI ADCP.

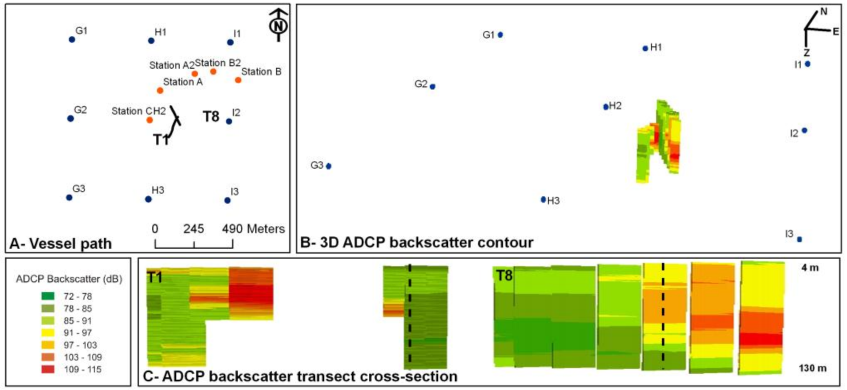


Figure 3.39 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 1 and 8 of Survey 2 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

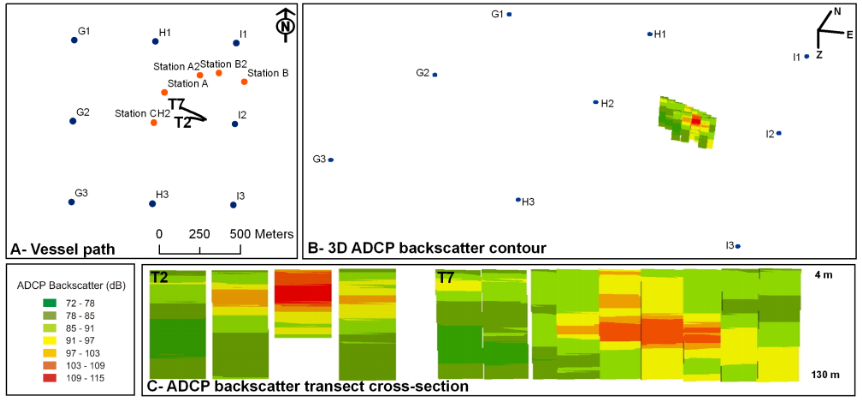


Figure 3.40Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 2 and 7 of Survey 2 collected by the vessel-mounted 250 kHz RDI ADCP.

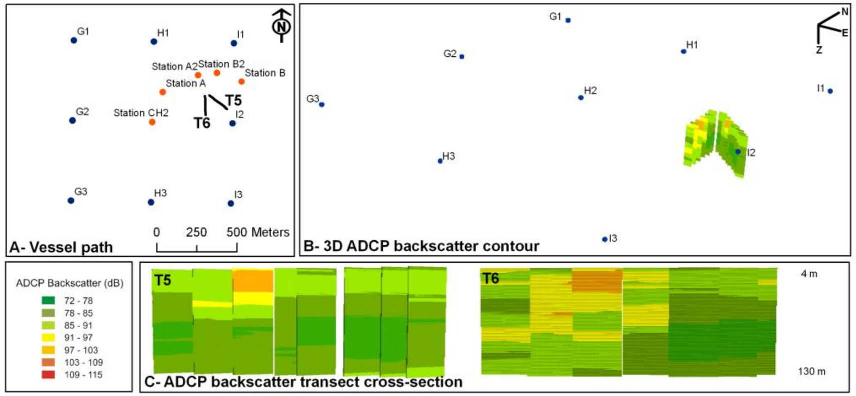


Figure 3.41 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 5 and 6 of Survey 2 collected by the vessel-mounted 250 kHz RDI ADCP.

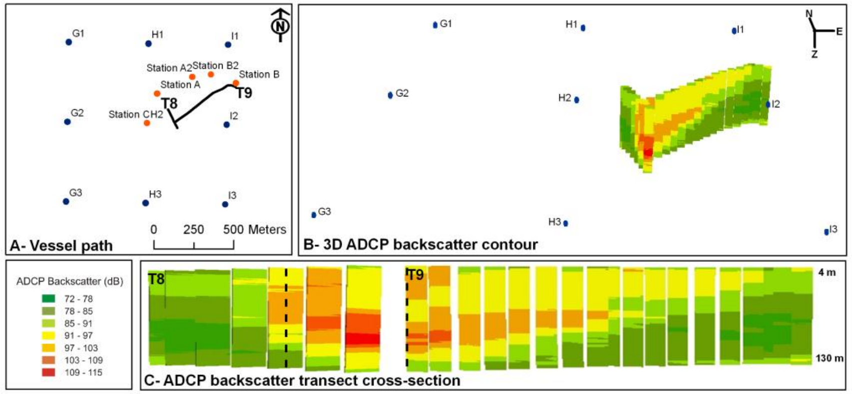


Figure 3.42 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 8 and 9 of Survey 2 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

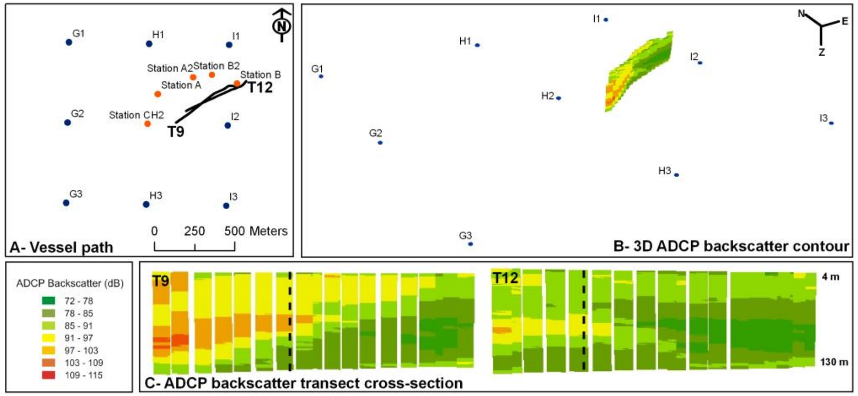


Figure 3.43 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 9 and 12 of Survey 2 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

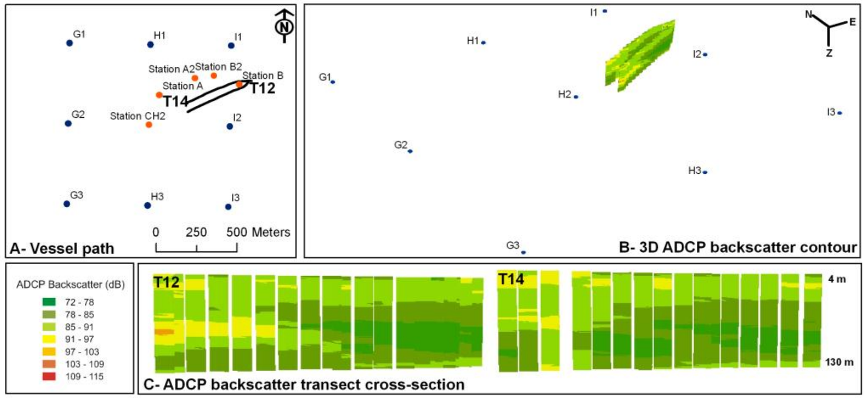


Figure 3.44 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 12 and 14 of Survey 2 collected by the vessel-mounted 250 kHz RDI ADCP.

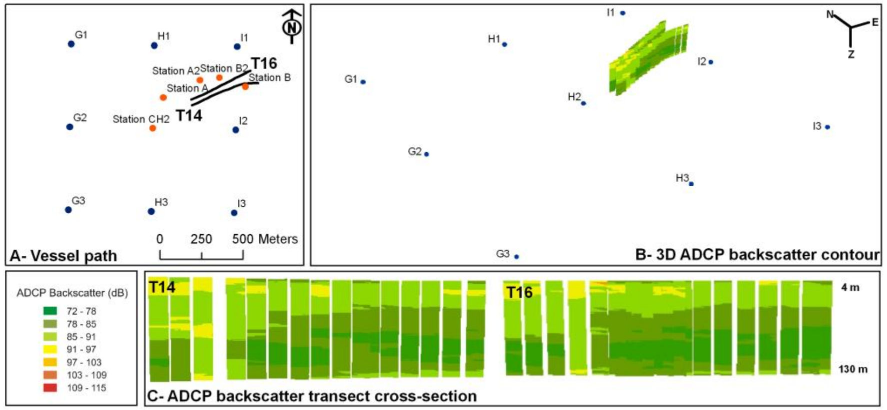


Figure 3.45 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 14 and 16 of Survey 2 collected by the vessel-mounted 250 kHz RDI ADCP.

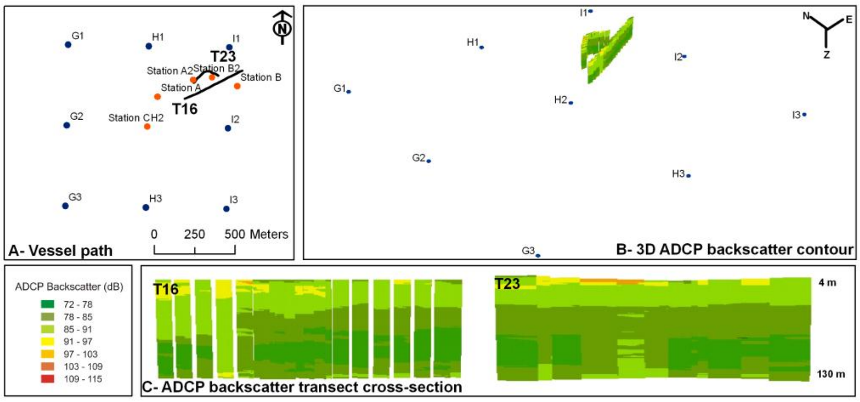


Figure 3.46 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 16 and 23 of Survey 2 collected by the vessel-mounted 250 kHz RDI ADCP.

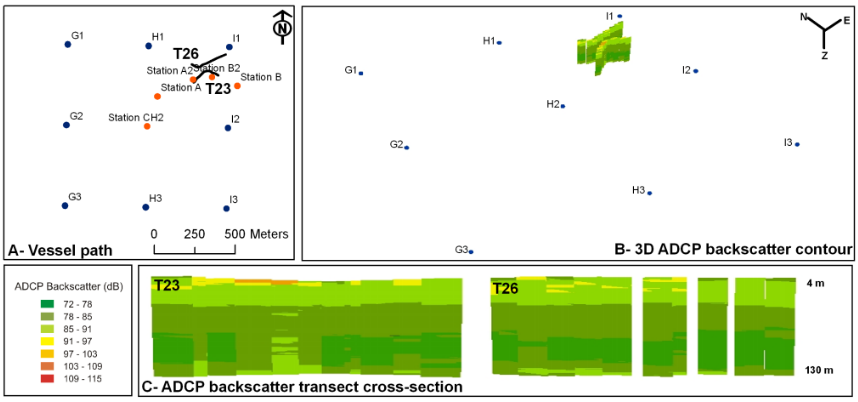


Figure 3.47 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 23 and 26 of Survey 2 collected by the vessel-mounted 250 kHz RDI ADCP.

Survey 3

Observations of the disposal plume characteristics based on ADCP backscatter data are tabulated in Table 3.11. Figures 3.48 – 3.59 show ADCP backscatter data recorded during the third plume monitoring survey on April 21 2010.

The following summarises the main observations from ADCP backscatter data recorded in Survey 3:

i. Immediately after release, the disposed material landed 50-100 m south of H2. Lateral spreading of the entrained material along the seafloor was minimal;

ii. After 20 min, entrained material had dispersed towards the east with increasing distance closer to the surface (the surface component was recorded approximately 250 m east of H2 by this point);

iii. Occurring around the same time was the indication of increased dispersion at approximately 100 m water depth (this was observed as far as 400 m east of H2 20 min after disposal). This dispersion is likely the result of elevated current speeds rather than a density layer because CTD profiles did not show density stratification at 100 m;

iv. 35 min after disposal, the surface component was detected ~600 m northeast of H2, but concentrations were only just above background levels;

v. The dispersion of material at 100 m water depth appears to have persisted in varying degrees of time after disposal and with distance from H2 (i.e. it was not detected in all transects recorded >1 hour after disposal and only in one transect recorded >1000 m northeast of H2).

Table 3.11 Post-disposal plume characteristics observed from ADCP backscatter data recorded during Survey 3.

Survey 3: April 21 2010							
Tran-sect	**Figure No.**	**Post-disposal time (min)**	**Location in water column**	**Geographic location (from H2)***	**Component**	**Dimensions***	**Comments**
2	3.46, 3.47 & 3.57	5-10	Throughout	0-250 m SE	Main & entrained	125 m NW-SE	Blank ensembles indicate blocked data; represents very high density main component during descent
3	3.46 & 3.48	10	Throughout	0-75 m SE	Entrained	75 m NW-SE	Entrained material throughout water column in high concentration; width of plume is wider at the seabed indicating some lateral spread and mixing after impact of the main component
4	3.47, 3.49 & 3.53	10-15	Throughout	125 m ENE	Entrained	50 m NW-SE	Similar to T3; NE edge of entrained material; turbidity is somewhat diluted 5 min later and slightly further from H2
5	3.48	15-20	Throughout	0-50 m S	Entrained	100 m N-S	Similar to T3 and T5; entrained material, remaining close to release location with some spread closer to the seafloor, but decreasing in concentration with time
6	3.49-3.51	20	Throughout	0-200 m E	Entrained & dispersed	200 m E-W	Cross-section of the length of entrained material dispersed in the direction of the hopper path; densest at mid-column depths; appears to be some increased dispersion at ~100 m water depth
7	3.50 & 3.52	25	100 m	200-500 m SE	dispersed	At least 500 m SW-NE	Small amount of material dispersed at ~100 m water depth; highest concentration at this depth was located

							400 m east of H2
9	3.51 & 3.54	35	Throughout	100-600 m NE	dispersed	500 m SW-NE	Similar to T6; very low concentration surface component dispersed 250 m further east 15 min after T6; dispersion at 100 m water depth is not apparent beyond 250 m east of H2
10	3.52 & 3.56	40-50	Surface & 100 m	0-750 m NE	dispersed	n/a	Material dispersed to the NE is close to background turbidity; a small pulse of low turbidity material occurs ~700 m NE of H2, but dispersion at 100 m water depth does not occur beyond 500 m NE of H2
11	3.53 & 3.57	50-55	Surface & 100 m	100-250 m SE	dispersed	n/a	Almost an 60 min after disposal, turbidity is almost at background levels; it is still somewhat elevated at the surface as well as at 100 m water depth
12	3.54	55-60	Surface & 100 m	300-500 m ENE	dispersed	n/a	Similar to T10, pulse of material at the surface 500 m NE of H2 is still present, but material at 100 m water depth has decreased in concentration
13	3.57	55-60	Surface	750 m NE	dispersed	n/a	Some low concentration surface material, but material at 100 m is not visible
14	3.55	60	n/a	800 m NE	n/a	n/a	Background levels
15	3.55 & 3.57	60-65	n/a	1000 m NE	n/a	n/a	Background levels
17	3.56 & 3.57	70-80	100 m	200-1250 m ENE	dispersed	n/a	Concentration is mostly background levels, with the exception of some material at the 100 m water depth (mostly within 200 m SE of H2 and some between 750 and 1000 m NE of H2)

*Measures are approximate

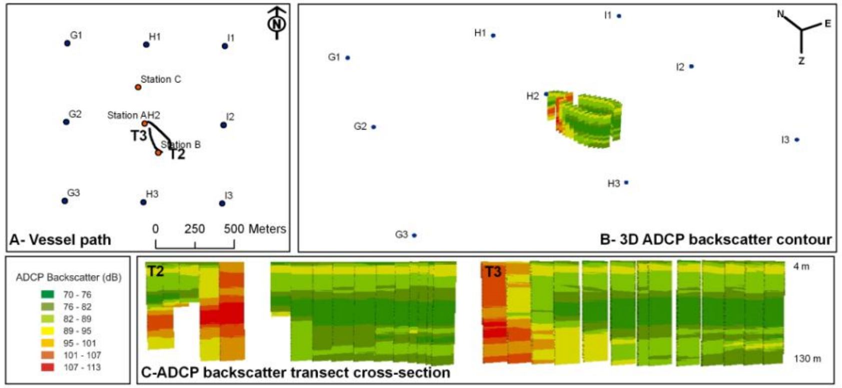


Figure 3.48 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 2 and 3 of Survey 3 collected by the vessel-mounted 250 kHz RDI ADCP.

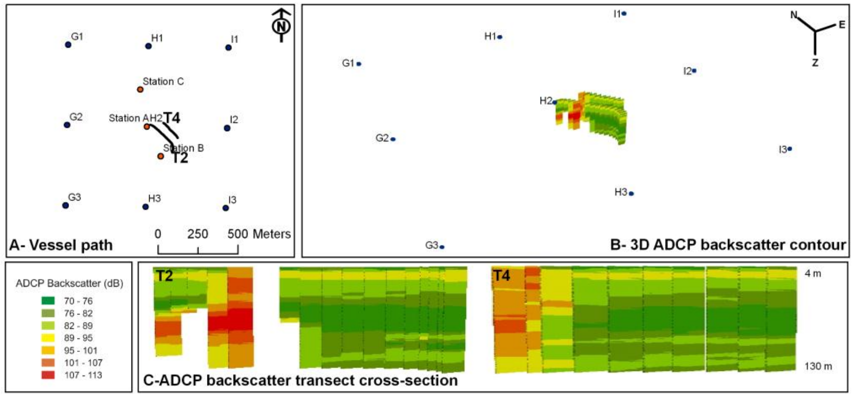


Figure 3.49 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 2 and 4 of Survey 3 collected by the vessel-mounted 250 kHz RDI ADCP.

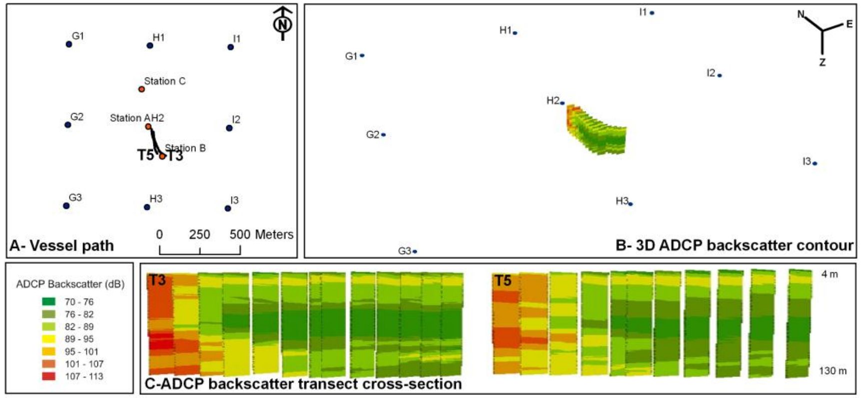


Figure 3.50 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 3 and 5 of Survey 3 collected by the vessel-mounted 250 kHz RDI ADCP.

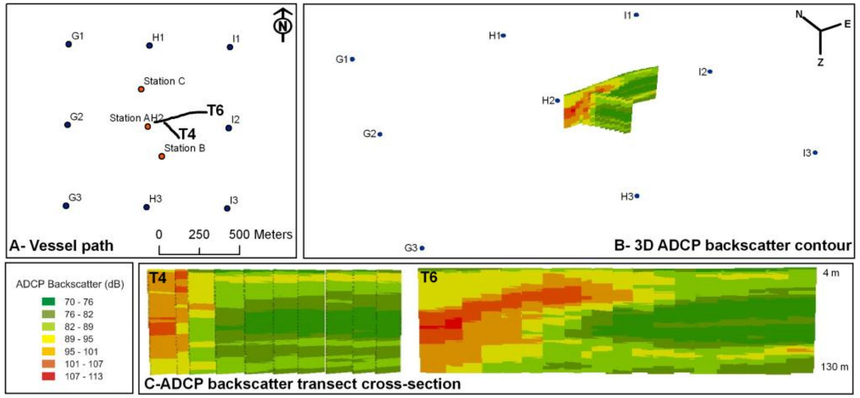


Figure 3.51 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 4 and 6 of Survey 3 collected by the vessel-mounted 250 kHz RDI ADCP.

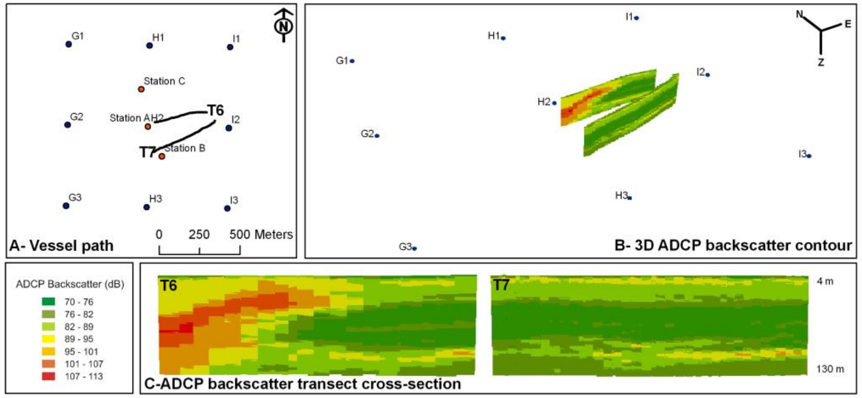


Figure 3.52 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 6 and 7 of Survey 3 collected by the vessel-mounted 250 kHz RDI ADCP.

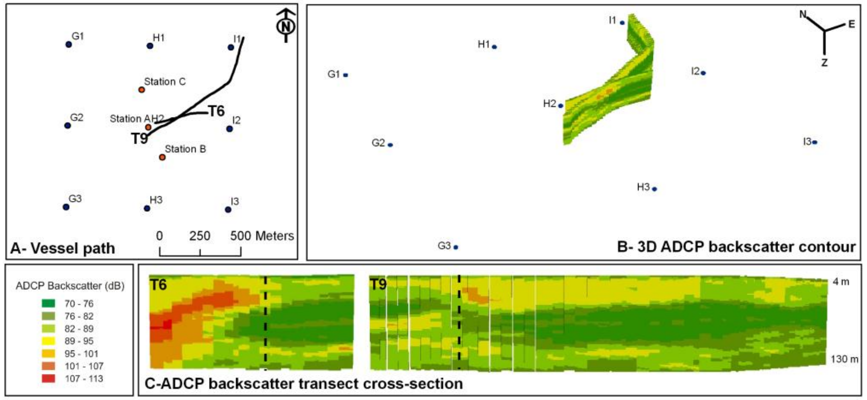


Figure 3.53 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 6 and 9 of Survey 3 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

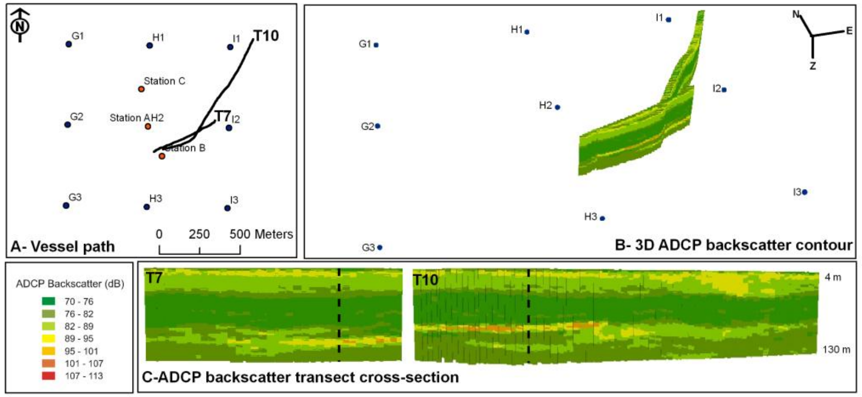


Figure 3.54 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 7 and 10 of Survey 3 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

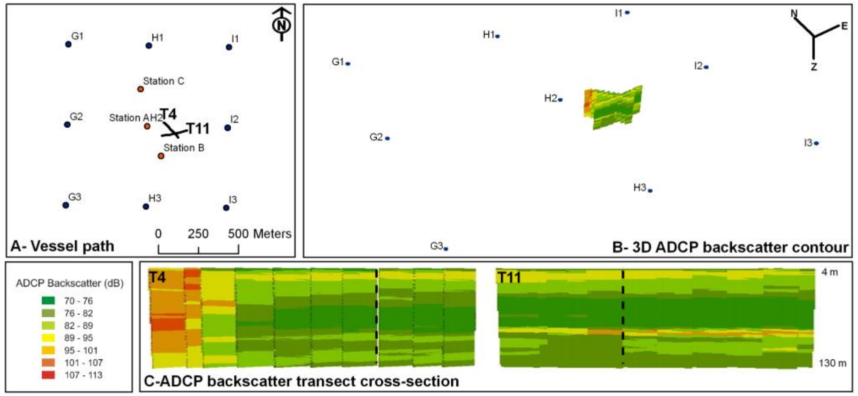


Figure 3.55 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 4 and 11 of Survey 3 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

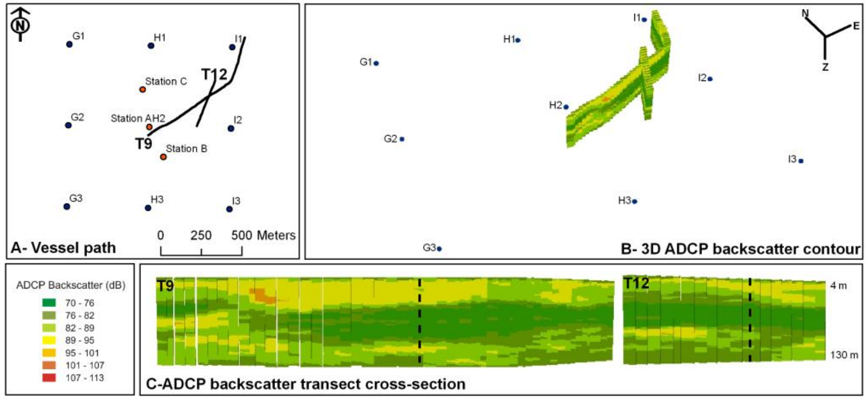


Figure 3.56 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 9 and 12 of Survey 3 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

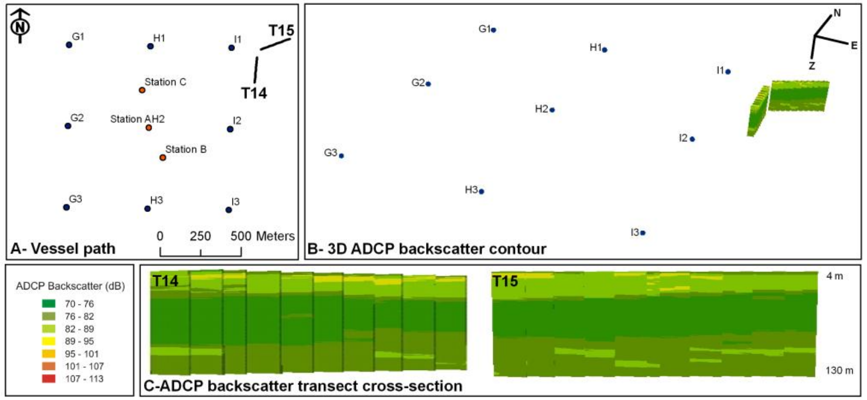


Figure 3.57 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 14 and 9 of Survey 3 collected by the vessel-mounted 250 kHz RDI ADCP.

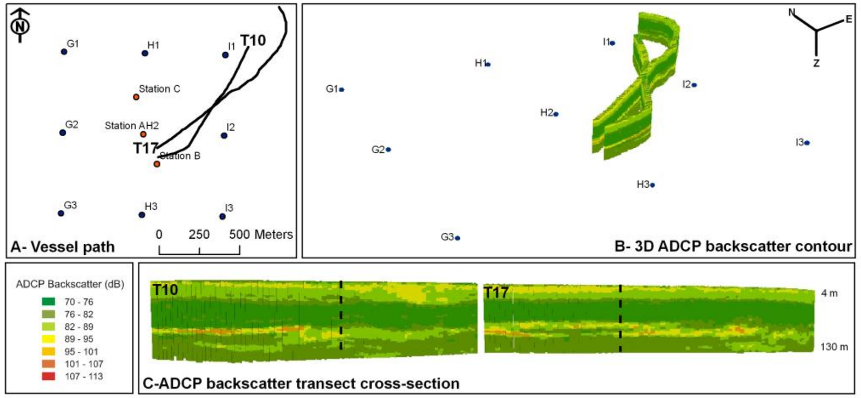


Figure 3.58 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 10 and 17 of Survey 3 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

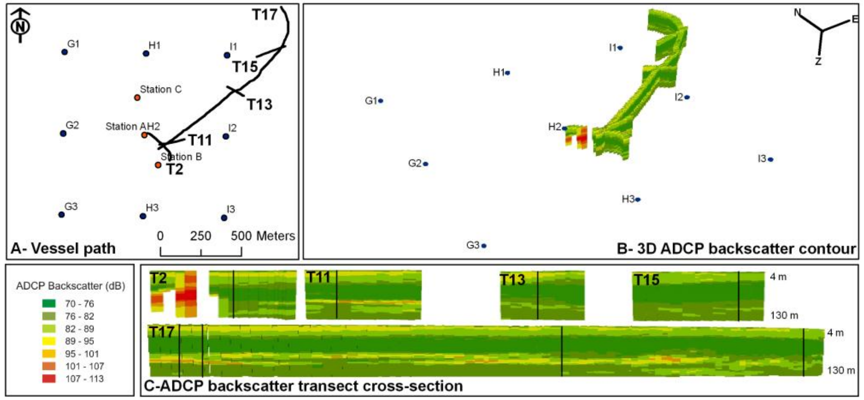


Figure 3.59 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 2, 11, 13, 15 and 17 of Survey 3 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by black line on (C).

Survey 4

Observations of the disposal plume characteristics based on ADCP backscatter data are tabulated in Table 3.12. Figures 3.60 – 3.71 show ADCP backscatter data recorded during the fourth plume monitoring survey on April 25 2010.

The following summarises the main observations from ADCP backscatter data recorded in Survey 4:

i. Immediately following release, the main component of the disposed material landed approximately 200 m southwest of H2 and entrained material spread out laterally along the bottom to the southeast for 150-200 m;

ii. Within 15 min of release, the surface component of the entrained material had drifted approximately 200 m north of where the main component landed (~200 m north of H2);

iii. After 40-50 min, the surface component had diluted significantly to just above background levels, but dispersed significantly away from the point of impact (it was detected some 400 m north and southwest of H2);

iv. The bottom component remained in the same position 60 min after disposal and by that time was diluted to just above background levels;

v. There was some indication of increased dispersion at approximately 100 m water depth to the north and east of where the main component deposited (~250 m northeast and 50-100 m south of H2), but turbidity in these areas was only just above background levels. This dispersion is likely the result of increased current speed rather than a density layer because CTD profiles showed no density stratification at 100 m.

Table 3.12 Post-disposal plume characteristics observed from ADCP backscatter data recorded during Survey 4.

Survey 4: April 25 2010							
Tran-sect	**Figure No.**	**Post-disposal time (min)**	**Location in water column**	**Geographic location (from H2)***	**Component**	**Dimensions***	**Comments**
1	3.58-3.60	5-10	Throughout	200 m SW	Main & entrained	150 m NW-SE	Blank ensembles indicate blocked data; represents very high density main component during descent
2	3.58 & 3.61	10	Throughout	100 m W	Dispersed	At least 50 m W-E	Most likely the edge of the entrained material; highest density near the surface indicating that settling has not occurred yet
3	3.61, 3.62 & 3.66	10-15	Throughout	100-200 m WNW	Dispersed	200 m SW-NE	Entrained surface component appears to have dispersed northwards from where the main component descended; densest near the surface
5	3.62	15-20	Throughout	200 m NW	Dispersed	80 m W-E	Cross-section of the width of T3; density at the surface is diminished compared to T3 taken 5 min prior
6	3.64, 3.65 & 3.67	20	Throughout	100-200 m SW	Entrained & dispersed	300 m NW-SE	Entrained material at seabed after impact; density closer to the bottom is significantly higher than that at the surface; dispersion mainly at surface
7	3.63	25	Throughout	200-250 m SW	Entrained	400 m NW-SE (W-E)	Similar to T6; 5 min later plume at sea bed has increased in length by ~100 m, but the density had decreased indicating rapid settling.
8	3.63	35	Throughout	200 m SW	Entrained	200 m SW-NE	Cross-section of the width of T7; bottom plume appears to be longest (~ 400 m) from NW-SE with a width of ~200 m SW-NE; surface entrained material appears to

							be greatly diluted in this area (compared to T3 recorded 20 min prior)
9	3.64	40-50	Throughout	100-200 m WNW	Entrained	375 m SW-NE	Similar to T8; density of suspended material is diminished throughout the water column; entrained material near the bottom appears in the same location , but the surface component has drifted ~400 m NE and SW
11	3.65	50-55	Throughout	100-250 m WNW	Dispersed	n/a	Edge of the bottom entrained component; almost 1 hour after disposal, the bottom plume has remained very close to where the main component landed; surface component has drifted further, but it is only just above background levels
13	3.66	55-60	Throughout	100 m NW	Dispersed	n/a	Concentrations are barely above background; surface component stronger NW of H2; appears to be some faster dispersion at ~100 m water depth ESE of H2
14	3.67 & 3.68	55-60	Throughout	50-300 m WSW	Dispersed	n/a	Surface component strongest WSW of H2; bottom component remaining south of H2; increased dilution throughout water column
15	3.68 & 3.69	60	Surface & 100 m	200-400 m W	Dispersed	n/a	Surface component still visible to the west of H2; bottom component barely visible at this location, but dispersion at 100 m is still visible
17	3.69	60-65	Surface	250-600 m W	Dispersed	n/a	Bottom component is not visible at this location; it appears that there may still be some elevated turbidity at the surface west of H2, but it is difficult to discern plume from background levels

*Measures are approximate

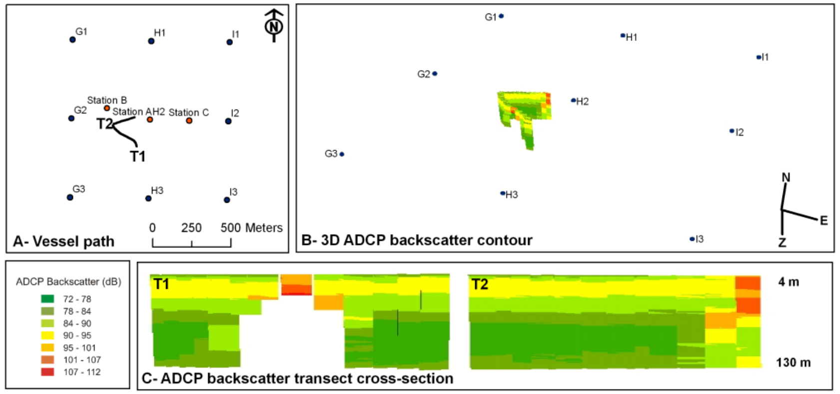


Figure 3.60 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 1 and 2 of Survey 4 collected by the vessel-mounted 250 kHz RDI ADCP.

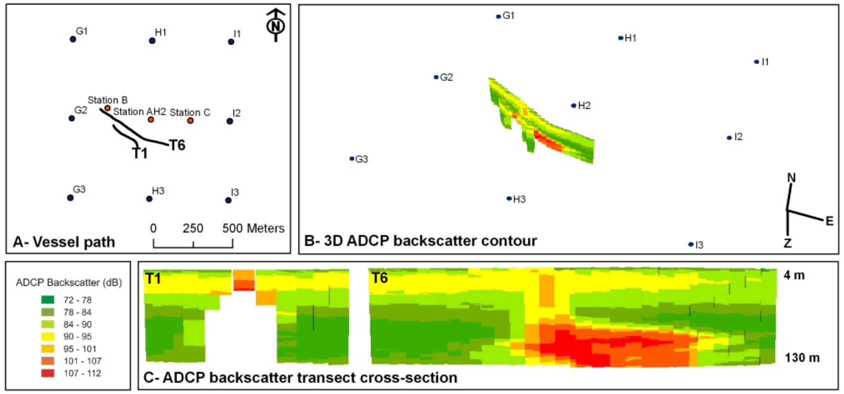


Figure 3.61 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 1 and 6 of Survey 4 collected by the vessel-mounted 250 kHz RDI ADCP.

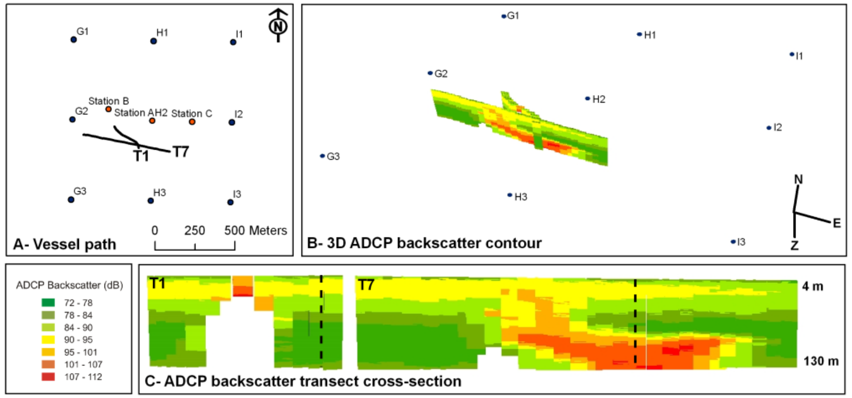


Figure 3.62 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 1 and 7 of Survey 4 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

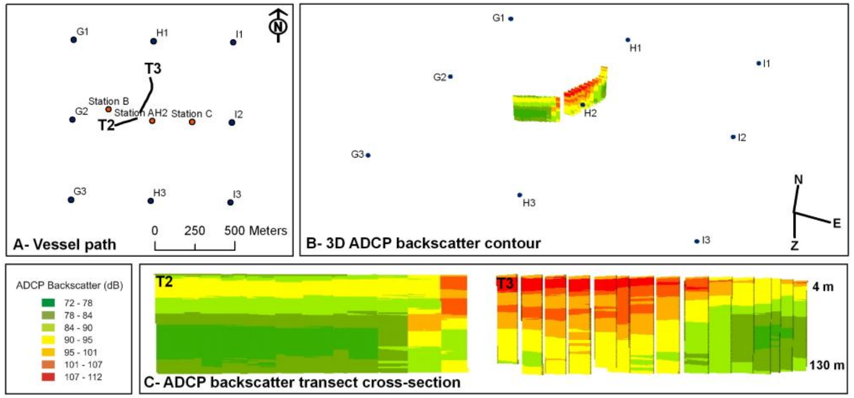


Figure 3.63 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 2 and 3 of Survey 4 collected by the vessel-mounted 250 kHz RDI ADCP.

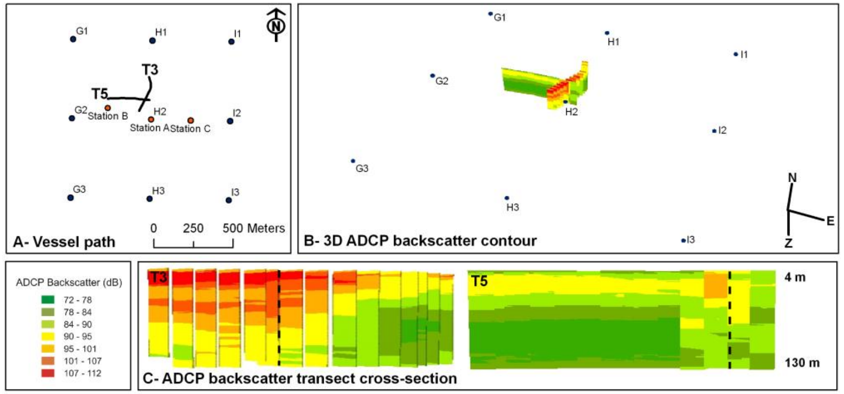


Figure 3.64 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 7 and 8 of Survey 4 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

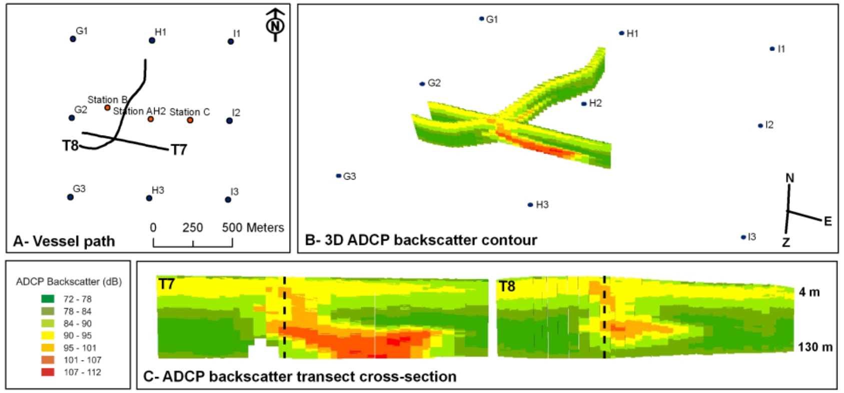


Figure 3.65 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 7 and 8 of Survey 4 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

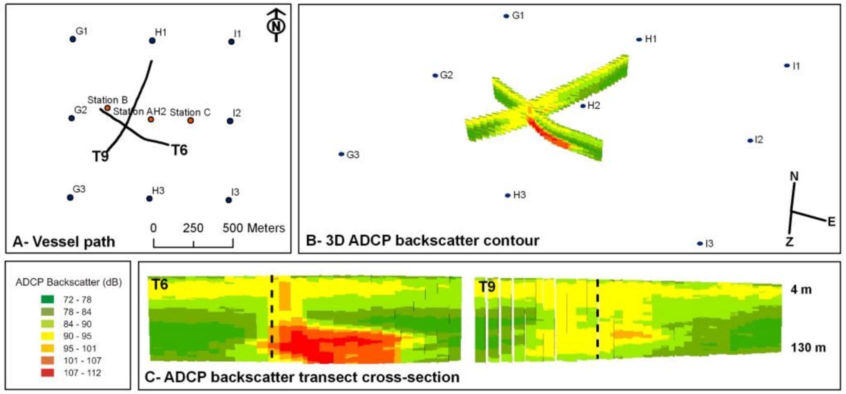


Figure 3.66 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 6 and 9 of Survey 4 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

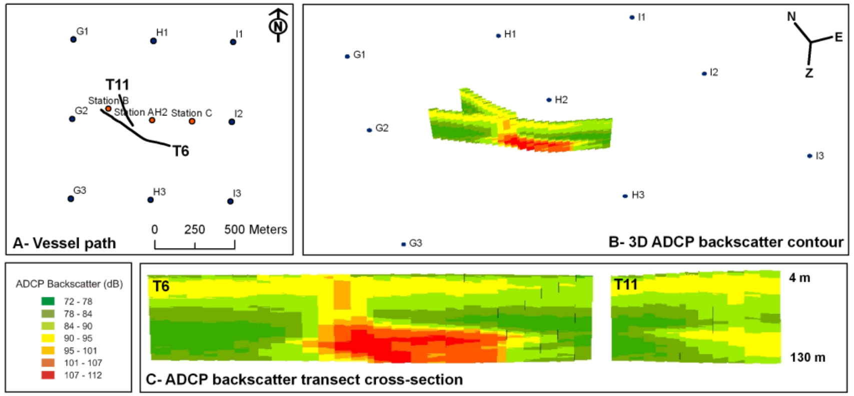


Figure 3.67 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 6 and 11 of Survey 4 collected by the vessel-mounted 250 kHz RDI ADCP.

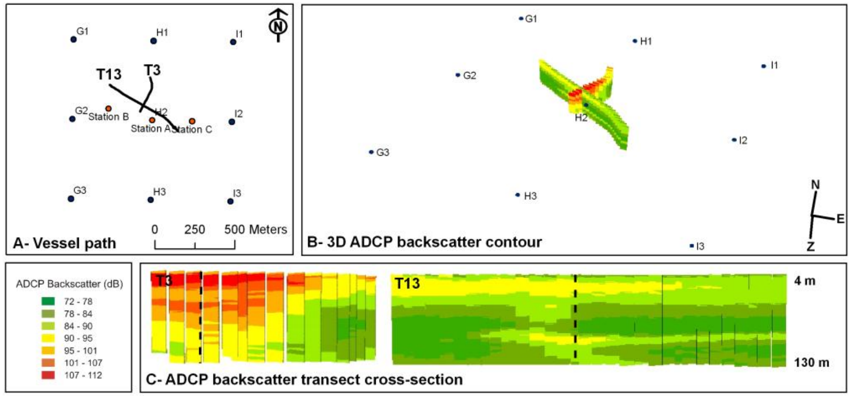


Figure 3.68 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 3 and 13 of Survey 4 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

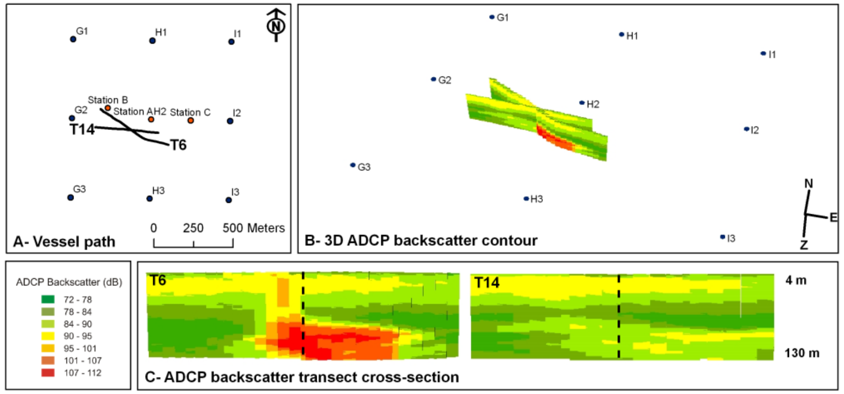


Figure 3.69 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 6 and 14 of Survey 4 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

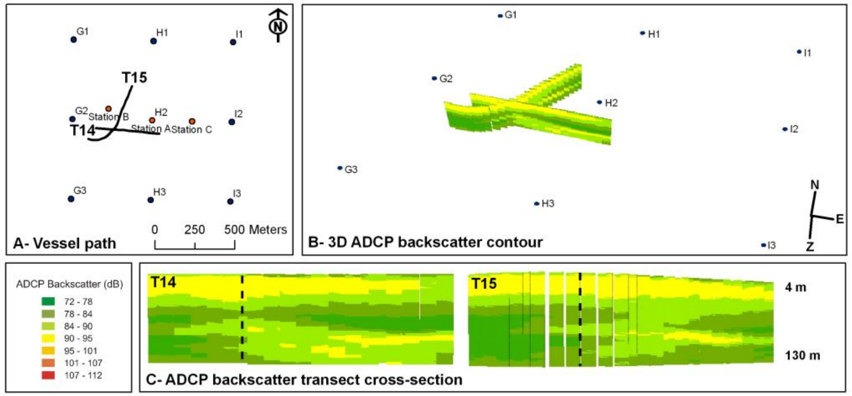


Figure 3.70 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 14 and 15 of Survey 4 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

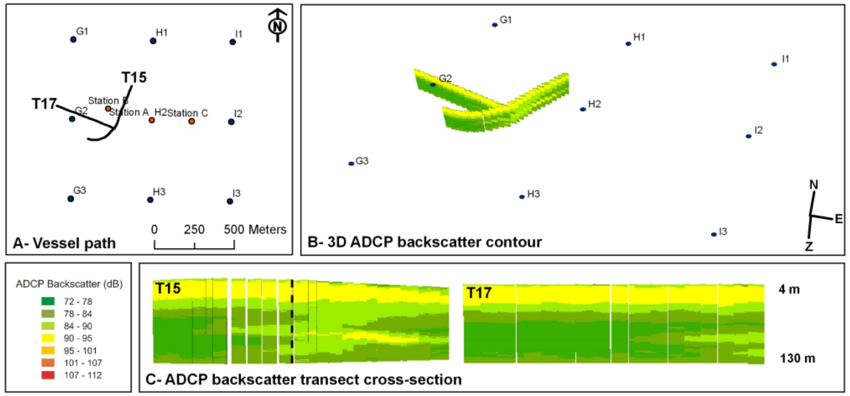


Figure 3.71 Vessel path (A), 3D backscatter contour profiles (B) and backscatter cross-sections (C) for transects 15 and 17 of Survey 4 collected by the vessel-mounted 250 kHz RDI ADCP. Transect intersection indicated by dashed line on (C).

3.3.6 Estimated deposition footprints

Figure 3.72 shows multibeam echosounder (MBES) backscatter data collected at the site following completion of disposal operations in the 1000 m X 1000 m area surrounding the release location (H2) (see Report 2). At the top left is a top-view of the MBES backscatter data with coloured rings highlighting regions of higher intensity/lighter colour backscatter signal (presumed to be deposited material). On the right, geo-referenced ADCP backscatter transects are superimposed on the MBES backscatter data. Transects 11, 8, 3 and 6, illustrate high density suspended sediment material at or near the seabed in the locality of higher intensity MBES backscatter data. The correspondence of the ADCP and MBES backscatter data suggests that the point of impact estimations for each of the four disposals described in Tables 3.9-3.12 are valid.

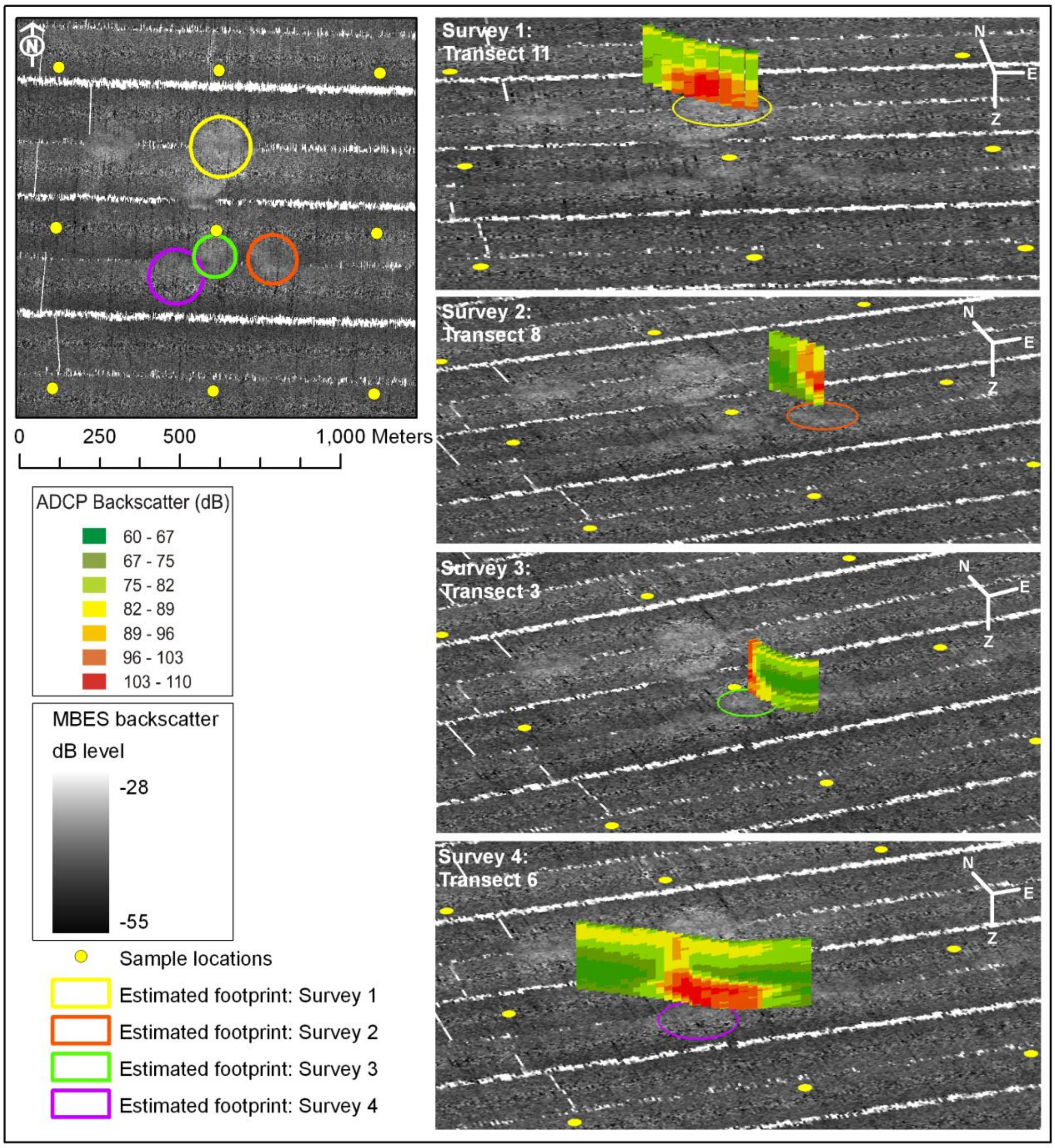


Figure 3.72 MBES backscatter map of the 1000 m X 1000 m surrounding the disposal location (left). Coloured rings highlight regions of deposited material (areas of higher intensity/lighter colour backscatter signal) that correspond to material "touchdown" seen in ADCP backscatter transects 11, 8, 3 & 6 from Surveys 1, 2, 3 & 4, respectively (right side).

3.3.7 Plume dispersion patterns

The main objective of the plume monitoring surveys was to determine whether or not the disposal plume could be detected beyond the boundaries of the disposal site. The boundary of the disposal site has been designated as the area within a 1500 m radius of the centre (H2). Datasets recorded by the ADCP and BIOFISH most closely tracked the plume and thus was used to determine the detection limit over the four occasions that it was monitored. Data was first grouped by distance from centre as follows: 0-100 m, 100-200 m, 200-300 m, 300-400 m, 400-500 m, and 500-700 m. Figure 3.73 shows the locations of the collected data in relation to the grouping distances for each survey. ADCP and BIOFISH transect data was assigned to a group based on the distance of each transect from centre. In the instance that the transect spread over multiple distance categories, it was split into the respective groups.

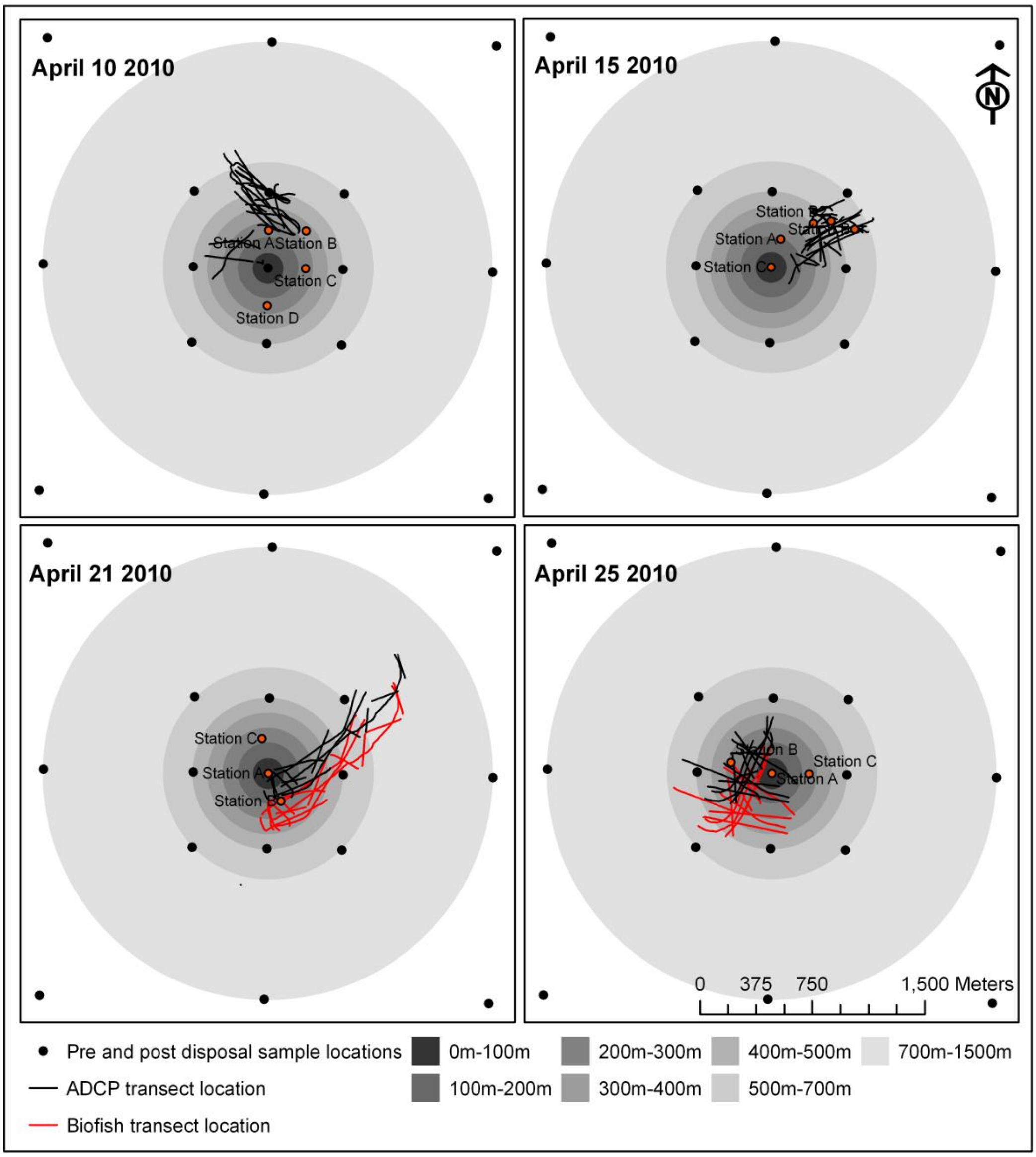


Figure 3.73 Locations of sampling stations A, B, C & D as well as ADCP and biofish transect locations in relation to distance from centre (disposal location) for each of the 4 surveys. For analyses, data was classified as 0-100m, 100-200m, 200-300m, 300-400m, 400-500m, 500-700m, or 700-1500m from centre.

As the BIOFISH was towed approximately 150 m behind the main survey vessel (where the ADCP was mounted), there was a time lag between ADCP and BIOFISH data. This time lag is illustrated in Figures 3.74-3.77 where surface plume conditions recorded by the BIOFISH appear shifted from that recorded by the ADCP. Furthermore, because of the distance between the BIOFISH and the ADCP and because the BIOFISH only recorded surface data, a greater proportion of the BIOFISH data records were that of ambient conditions rather than plume conditions. Despite this, data from both the BIOFISH as well as the ADCP showed similar patterns in plume concentration.

Combined survey data recorded by the BIOFISH and the ADCP are plotted by distance from centre in Figures 3.78 and 3.79, respectively. As a result of its distance from the ADCP and because it was only deployed during Surveys 3 and 4, very little of the BIOFISH data sets were recorded in the first two distance groups which have accordingly been excluded from Figure 3.78. Generally though, both data sets show a pattern that indicates decreasing turbidity with distance from centre. Due to the lower proportion of plume data in the BIOFISH datasets, plume conditions are mainly represented as outliers (red '+' symbol). These records reflect a decrease in turbidity with distance from centre, with the exception of a possible true outlier in the 700-1500 m distance group. The pattern is more obvious in the ADCP backscatter dataset (Figure 3.79). The mean level for each distance group (blue horizontal line intersecting each box) consistently decreases with distance from centre. Plume turbidity decreased to background levels (ranging from 60-80 dB (see Figure 3.80)) 400-500 m from centre.

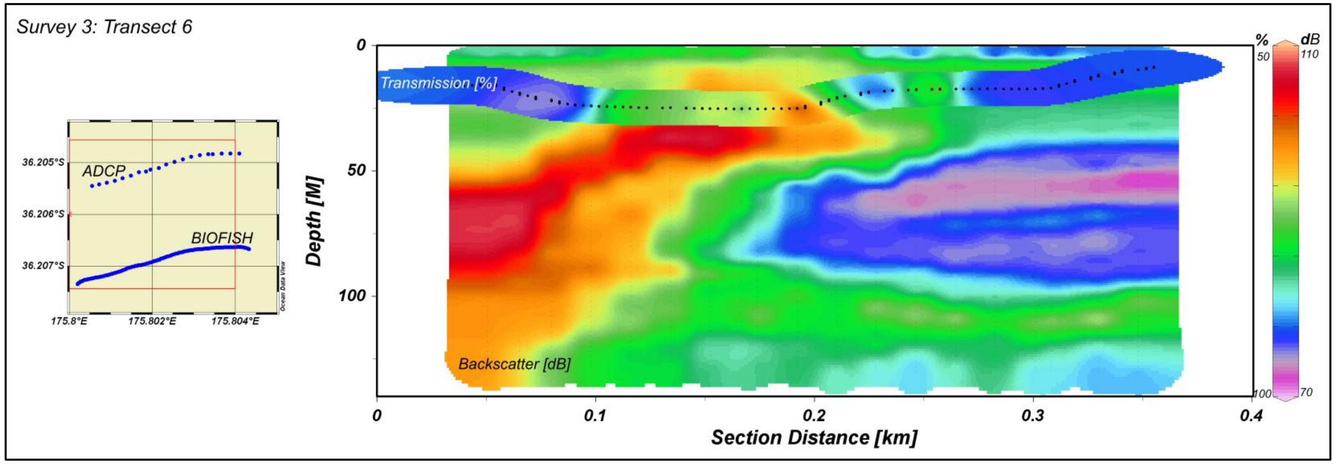


Figure 3.74 Transect 6 ADCP backscatter (dB) data super-imposed with BIOFISH transmission (%) data recorded during Survey 3 (inset: top view of transect locations).

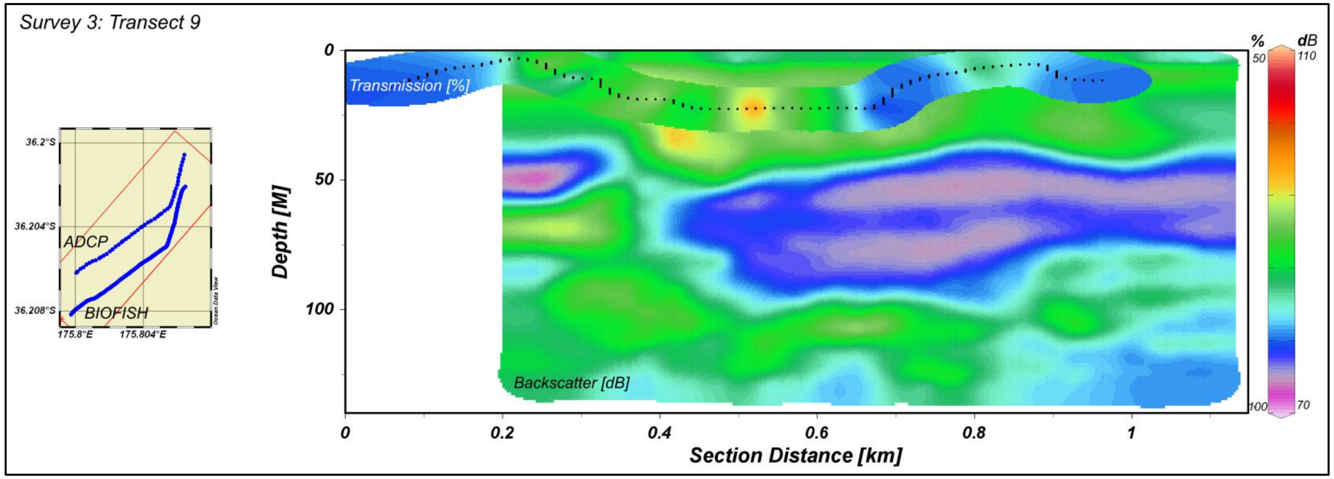


Figure 3.75 Transect 9 ADCP backscatter (dB) data super-imposed with BIOFISH transmission (%) data recorded during Survey 3 (inset: top view of transect locations).

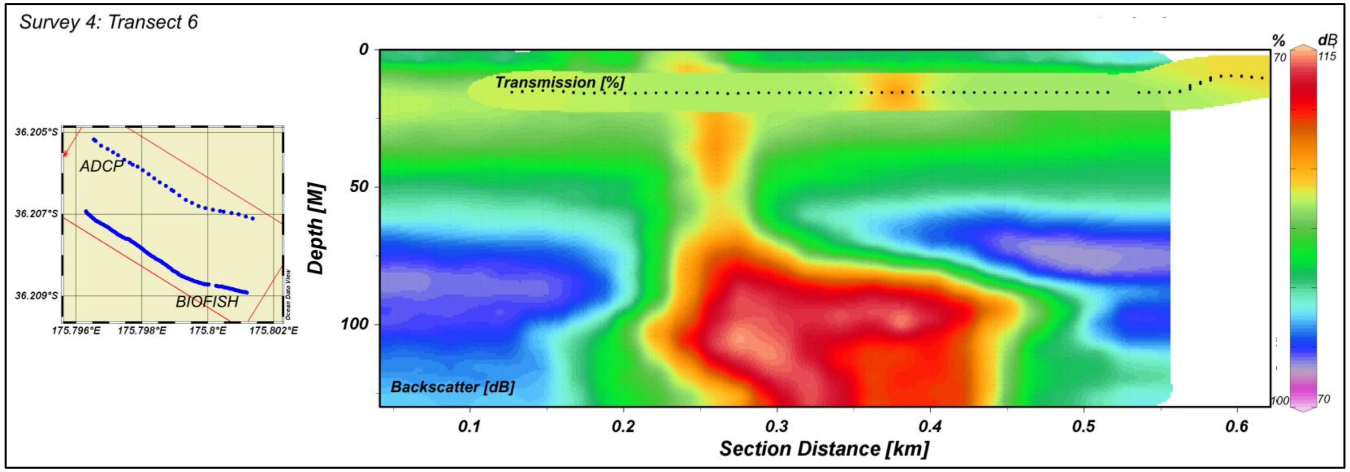


Figure 3.76 Transect 6 ADCP backscatter (dB) data super-imposed with BIOFISH transmission (%) data recorded during Survey 4 (inset: top view of transect locations).

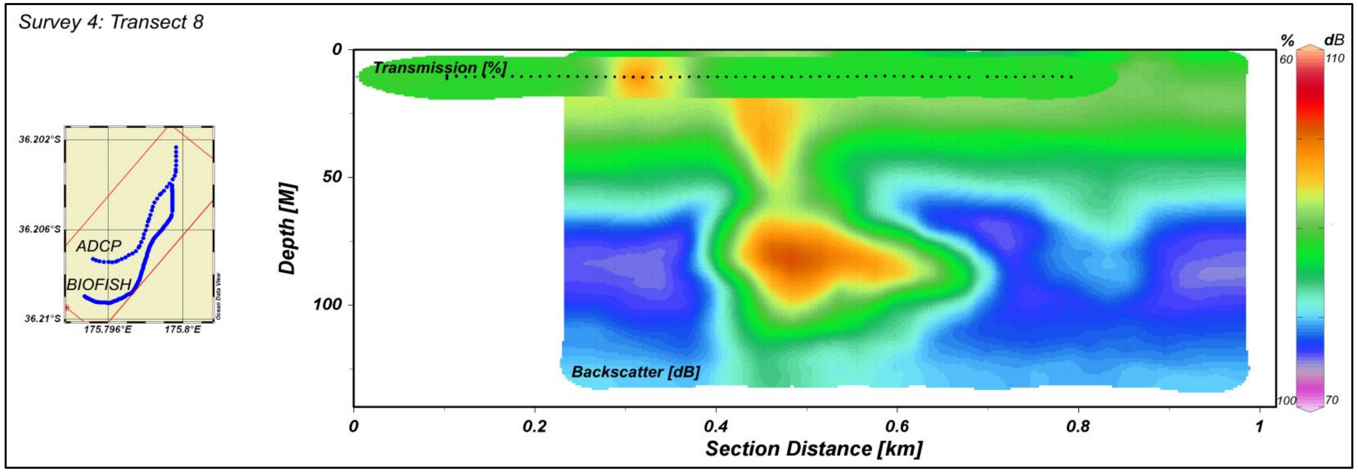


Figure 3.77 Transect 8 ADCP backscatter (dB) data super-imposed with BIOFISH transmission (%) data recorded during Survey 4 (inset: top view of transect locations).

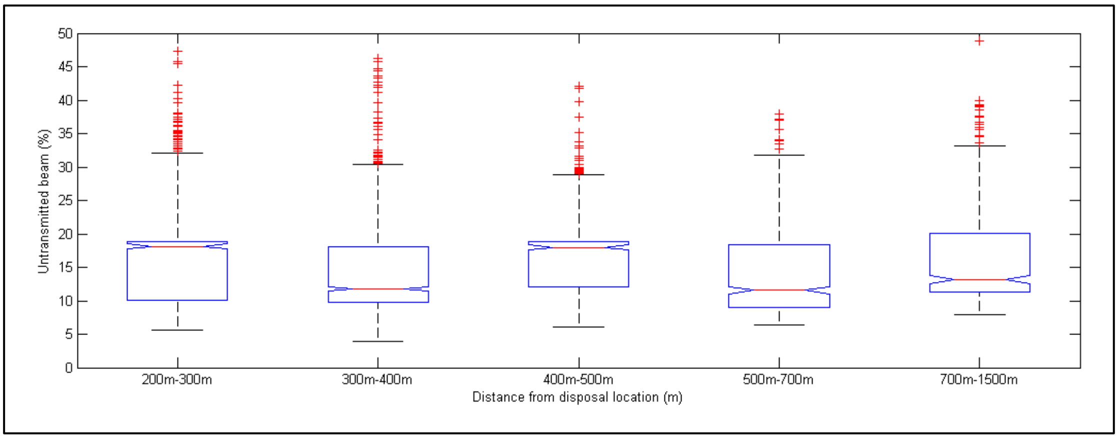


Figure 3.78 Notch plot of grouped light transmission data (% un-transmitted beam) collected using the BIOFISH during surveys 3 & 4.

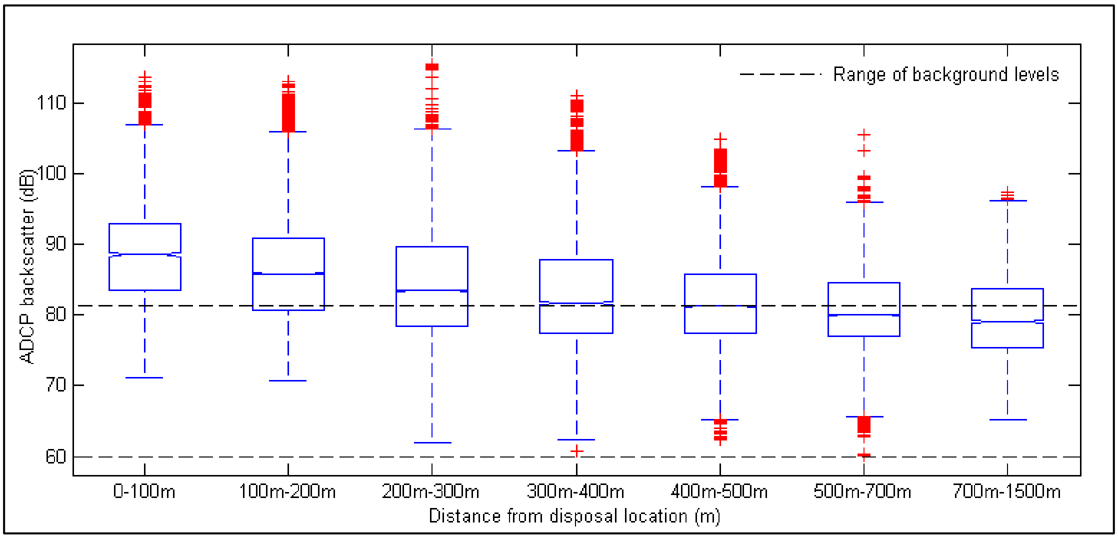


Figure 3.79 Notch plot of grouped ADCP backscatter data (dB) for surveys1-4. Black dashed lines indicate the range of background dB levels (see Figure 3.78).

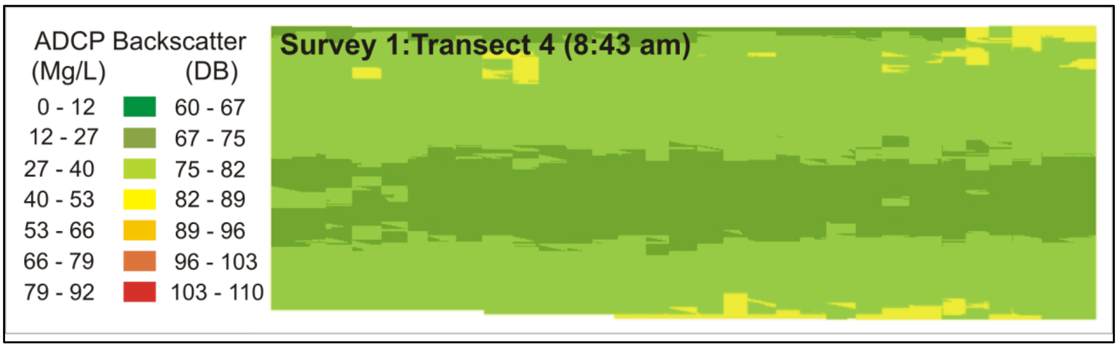


Figure 3.80 ADCP backscatter cross-section of transect 4 of Survey 1 collected at 8:43 am prior to disposal of dredged material. The range of dB (~60-82) is indicative of the background turbidity levels at the disposal site.

3.4 CONCLUSIONS

3.4.1 Plume Dispersion

<u>Survey 1: April 10 2010</u>

Conditions:

- Tide: Early flood
- Wind: SE, 10 knots
- Stratification: slight density gradient at 70 m
- Average drift current (0-30 m): NNW, 0.14 m/s
- Expected surface plume: ~500 m NNW in 1 hour

Observed Plume:

- Main component: deposited 200-250 m north of site centre (H2)
- Bottom entrained component: remained 250 m north of H2 and concentrations were barely above background turbidity levels 50 min after disposal
- Surface dispersed component: drifted north from H2 and after 50 min, concentrations only slightly above background were detected ~600 m north of H2

<u>Survey 2: April 15 2010</u>

Conditions:

- Tide: Mid-ebb
- Wind: SW, 10-15 knots
- Stratification: slight density gradient at 80 m
- Average drift current (0-30 m): NE, 0.175 m/s
- Expected surface plume:~700 m NE in 1 hour

Observed Plume:

- Main component: deposited 250 m southeast of H2
- Bottom entrained component: drifted ~250 m north from point of impact and decreased to background turbidity levels after 1 hour

- Surface dispersed component: drifted northeast from H2 and was not detected further than 750 m after 1 hour.

Survey 3: April 21 2010

Conditions:

- Tide: Late flood
- Wind: SW, 5 knots
- Stratification: slight density gradient at 30 m
- Average drift current: SSW, 0.08 m/s
- Expected surface plume: ~250 m SSW in 1 hour

Observed Plume:

- Main component: deposited 50-100 m south of H2
- Bottom entrained component: minimal spreading of entrained material at the seafloor
- Surface dispersed component: after 35 min, slightly increased surface turbidity levels were detected ~600 m northeast of H2, but after 1 hour, the surface component was undetectable
- Increased dispersion at 100 m water depth was not significant beyond 400 m east of H2 and within that point turbidity was only just above background levels.

Survey 4: April 25 2010

Conditions:

- Tide: Early flood
- Wind: NE, 10 knots
- Stratification: slight density gradient at 80 m
- Average drift current: W, 0.03 m/s
- Expected surface plume: ~100 m W in 1 hour

Observed Plume:

- Main component: deposited 200 m SW of H2
- Bottom entrained component: spread 150-200 m south east of point of impact and was only just above background levels 1 hour after disposal.

- Surface dispersed component: drifted mostly north (~600 m) and slightly southwest of the point of impact; after 45 min plume concentrations were undetectable beyond a 400 m radius of H2.

Overall, surveys of the disposal events on 10, 15, 21, and 25 April showed that the main component of the disposed dredged material rapidly descended through the water column and deposited no more than 250 m away from the centre of the site (H2). Most likely, the variation observed in the point of impact of the main component of the disposed material depends on how close to the mark the towed hopper was when the material was released. Point of impact observations are supported by MBES backscatter data collected several months after completion of disposal operations. Thus, it is reasonable to assume that the main component of the disposed material deposits within seconds and within 250 m of the release location, and is not readily transported from its point of impact on the seafloor. The highest concentration of fine material entrained near the seabed by turbulence resulting from the impact of the main component of the dredged material was observed to remain within 200 m of the point of impact. This suspension decreased in concentration to background levels, most likely through settling, approximately 1 hour after disposal. Initially, the stationary bottom suspension was ‘connected’ to the surface by fines entrained throughout the water column during the descent process. After several minutes, displacement of these fines, mainly in the surface waters, usually in the direction of the drift current was apparent. Turbidity arising from these dispersed fines was only significant within approximately a 500-600 m radius of the disposal location. When drift currents were more substantial (e.g. Surveys 1 and 2), the surface plume seemed to have remained somewhat more compact and was dispersed in a more uniform direction, but still was mainly undetectable beyond the 500-600 m radius. When the drift current was slower (e.g. Surveys 3 and 4) the surface plume was more diffuse and dispersed over a larger area within the 500-600 m radius. There was no evidence that dispersion was influenced or affected by the slight density gradients observed at the site during each survey at varying water depths.

Based on these results, it is reasonable to assume that a plume arising from dredged material disposed at the centre of the proposed site will not be dispersed at detectable levels beyond the established boundary (1500 m radius) and in fact will remain well within it. There is potential for increased dispersion if material is disposed during stormy sea conditions, but safety limitations of the tug and hopper in such conditions means that most likely disposal at the site will only ever be undertaken during calm conditions.

3.4.2 Plume Monitoring Methodology

The most valuable data collected during each of the four plume monitoring surveys was backscatter data recorded by the ADCP system. This data provided reliable estimates of the location and concentration (inferred) of the plume through time and space both vertically and horizontally. As long as the plume is visible from the surface, the vessel and therefore the ADCP system can easily travel with the plume as it degrades through time allowing for accurate determination of its spatial extent.

While data collected through other means during the 4 surveys were descriptive, problems related to deployment, equipment function/sensitivity, and spatial coverage made use of those systems much less practical than the ADCP system. The relatively large spatial extent of the plume and its rapid degradation further illustrates this point.

Typically, suspended sediment concentration (SSC), determined based on water samples, is used to ground truth ADCP backscatter data because alone, backscatter is only indicative of plume concentration. However, with the present case, the resultant plumes were found to be very transient and often had SSC concentrations similar to that of background levels. Therefore, it was not feasible to collect enough water samples (i.e. at a resolution fine enough in time and space) to accurately correlate backscatter levels to SSC. Despite this shortcoming, however, the ADCP backscatter data recorded during each survey was ultimately regarded relative to the background level turbidity present at the site. It is not significant whether the background level turbidity is recorded in units of SSC or backscatter for the purposes of determining the temporal and spatial extent of the plume. Accordingly, for possible future plume monitoring surveys at the disposal site, it seems unnecessary to collect water samples and that ADCP backscatter data alone is sufficient for providing the necessary information about the disposal plume.

The following are recommendations for an amended methodology for future plume monitoring surveys should they be required:

i. Use an ADCP system with a frequency no higher than 300 kHZ and ensure that power and ping settings are appropriate for the significant water depth at the disposal site;

ii. Survey only the 1000 m^2 area surrounding the release location at the centre of the site;

iii. Record transects along a pre-assigned grid for at least an hour after release of dredged material as well as 2-3 transects near the centre of the site prior to release of material;

iv. Immediately after release of material, the survey should start at the centre of the site and initially follow subsequent transects in the quadrant where the plume is most visible to ensure maximum coverage at its early and most concentrated stages, the regular grid pattern should be carried out from there by traversing up and back across the 1000 m^2 area;

v. The assigned grid pattern should maximise coverage of the area during the short time that the plume is visible, while ensuring a fine enough data resolution to accurately represent the plume.

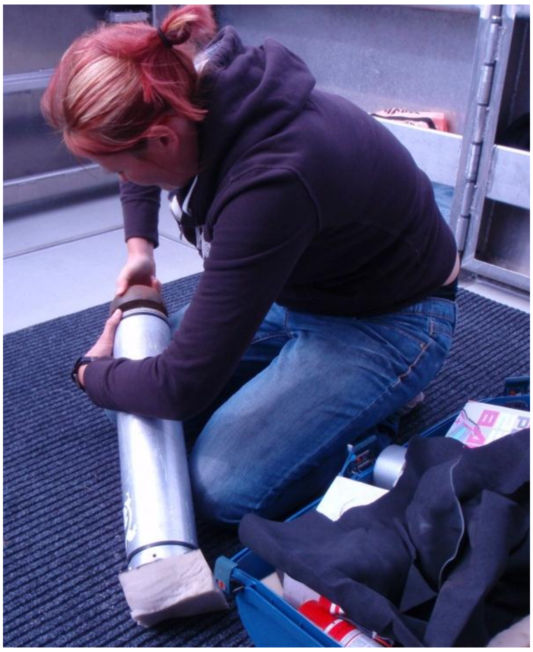
vi. The same grid pattern and methodology should be used on all future monitoring surveys for consistency in data comparison.

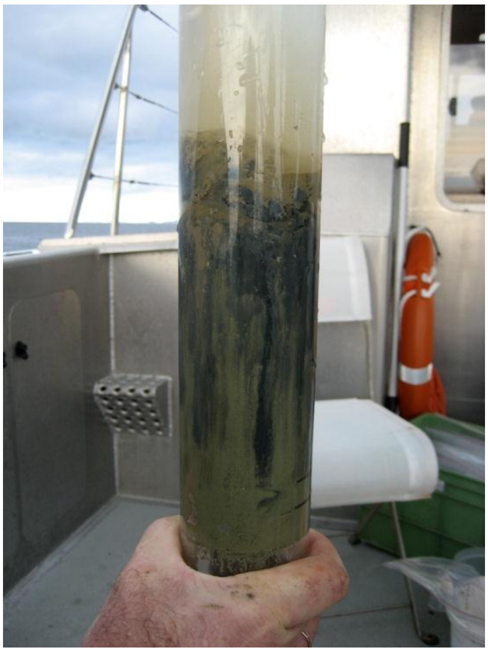
AUCKLAND MARINE DISPOSAL GROUND

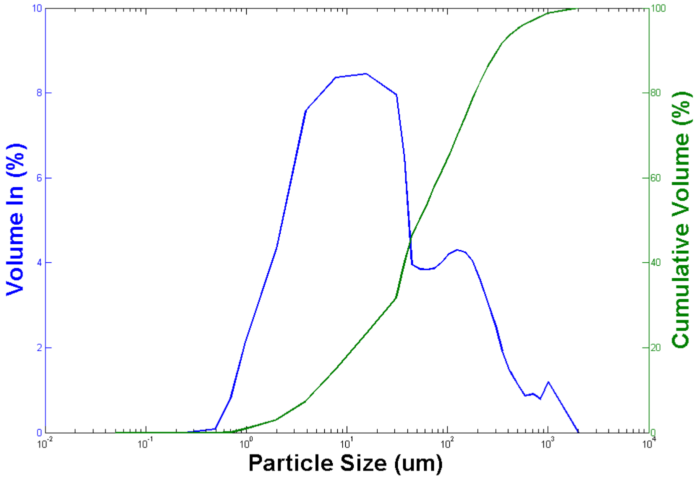
MONITORING SERIES

REPORT 4 SEDIMENT CHARACTERISTICS

February 2011







4.1 BACKGROUND

Characterisation of the sediment properties of the proposed site was undertaken before and after disposal of dredged material in March and April 2010. Through various methods, sediment texture, strength, and chemistry were assessed.

4.2 METHODOLOGY

Sediment cores were collected at the sites shown in Figure 4.1. Details of the sampling procedure are described in Report 1. The collected samples were used for both textural as well as chemical analysis. Textural analyses were undertaken on samples collected before and after disposal of dredged material at all sites shown in Figure 4.1 with the exception of Sites H2G2 and H2I2 which were only added during the post-disposal core collection survey, as well as Control Sites X1, X2, and X3, of which the pre-disposal cores were retained for benthic fauna identification (see Report 5). Of the cores collected during the post-disposal survey, sediment chemistry tests, including sediment heavy metal analysis, elutriate heavy metal analysis, and total petroleum hydrocarbon (TPH) analysis were undertaken on samples collected from Sites E2, G2, H2, H5, I2, and X2 (Figure 4.1).

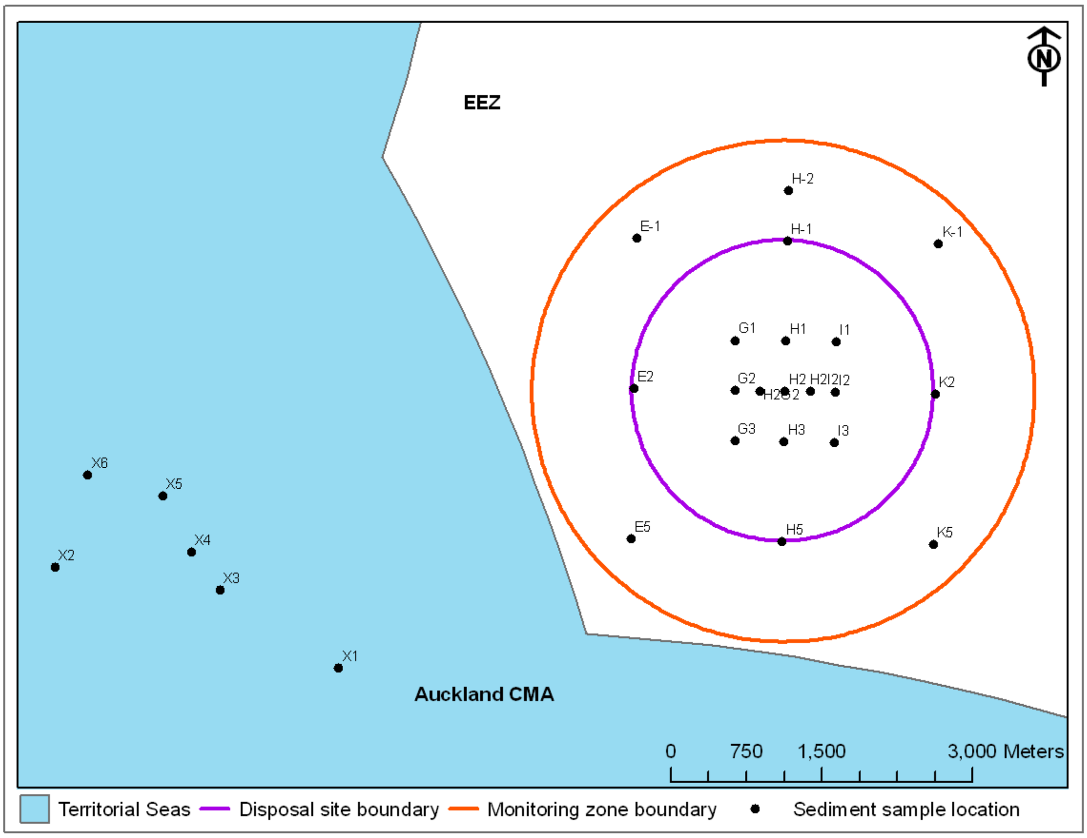


Figure 4.1 Map location of the proposed disposal site, monitoring zone, Territorial Sea/EEZ boundary, and locations where sediment cores were collected before and after disposal of 4800 m^3 of dredged material.

Textural analysis was undertaken using the University of Waikato Malvern Mastersizer 2000 particle analyser. Prior to analysis, samples were digested in 10% hydrogen peroxide to remove organic material which can skew grain size results.

Sediment chemistry analyses were undertaken by Hill Laboratories. Details on methods are included in the Appendix.

The geomechanical strength of the site sediment was assessed using the dynamic penetrometer *Nimrod* (Figure 4.2). This device is a portable probe capable of recording small scale vertical changes in sediment strength through the possibility of variable tip geometries (flat cylinder, hemisphere, or cone), the ability for true free-fall along with high-speed data acquisition, and the inclusion of four accelerometers varying in range and resolution (Stark et al. 2009a). Deployed by hand, *Nimrod* penetrates the seafloor after free-fall through the water column. Sensors measure deceleration and pressure over time after penetration of the seafloor allowing for the calculation of velocity and penetration depth (Stark et al. 2009a). Although vertical variation in sediment properties such as strength and density can be inferred through the deceleration-depth profiles, the impact velocity and in consequence the deceleration, is also influenced by water column effects (e.g. currents) and other deployment factors (e.g. tether drag) (Stoll et al. 2007; Stark and Wever 2008). Given these uncertainties, it has been considered more useful to assess bearing capacity and undrained shear strength (Aubeny and Shi, 2006; Stoll et al 2007; Stark et al. 2009b). Deceleration after the probe contacts the seafloor is proportional to the resistive force of the sediment which is dependent on its undrained shear strength (Stoll and Akal 1999). Following that principle, an approach first introduced by Dayal and Allen (1975) and advanced by Aubeny and Shi (2006) was used to determine the undrained shear strength from the deceleration profile at locations across the proposed site.

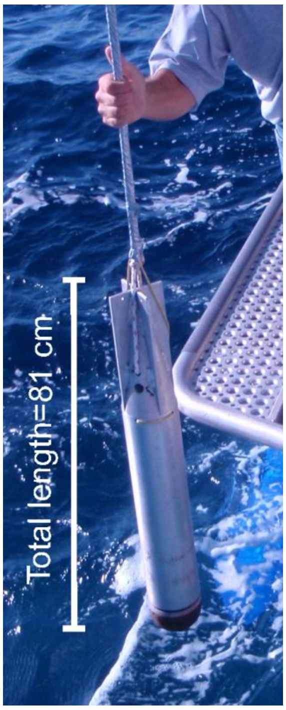


Figure 4.2 *Nimrod* being readied for a free-fall deployment (assembled with hemispherical tip).

The objective of the *Nimrod* survey was to provide additional data on the fate of the disposed material. It was thought that as is typically the case, the majority of the disposed material from each load would deposit on the seafloor close to the release location. As this main component would likely be composed of the dense blocks of material as well as lighter fluffy material deposited further away in the turbidity current, *Nimrod* could potentially record subtle variations in sediment strength as a result of deposited dredged material that would complement other post-disposal data such as MBES backscatter (see Report 2). However, due to time constraints *Nimrod* was not available for a post-disposal survey following disposal of the total 4800 m^3 of dredged material. Instead *Nimrod* was deployed at the site following disposal of loads 1 and 2. Load number 1, released on March 14 2010 was followed by a *Nimrod* survey two days later on March 16 2010. Load number 2, released on March 20 2010 was surveyed immediately and completed within 4 hours of the release of material. *Nimrod* was also deployed at the site prior to disposal to assess undisturbed sediment strength characteristics of the seafloor in the area of the site. Deployment locations are shown in Figure 4.3.

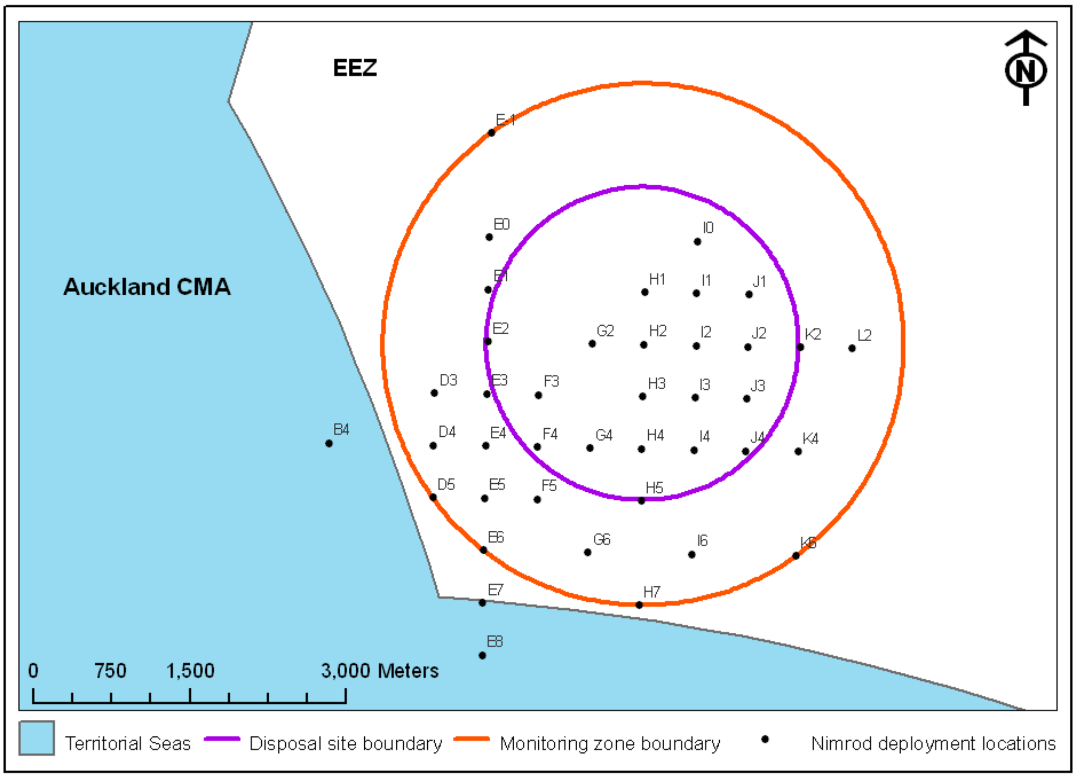


Figure 4.3 ***Nimrod*** **deployment locations including the boundaries of the disposal site and monitoring zone.**

For each deployment, acquired data was downloaded from the internal memory card and processed following the method described in Flaim *et al.* (*in press)* in order to derive vertical shear strength profiles for each deployment location. Following the *Nimrod* surveys, additional cores were collected at 5 randomly selected *Nimrod* deployment sites. Laboratory vane shear tests were undertaken on the collected cores and were used to verify the derived *Nimrod* shear strength profiles.

4.3 RESULTS

4.3.1 Sediment texture

Particle size data for each site sampled is shown in Table 4.1. Sites where no size analysis was undertaken are marked with a (-). Gray columns are the percent sum of all size classes smaller than 63 µm which make up the silt and clay sizes ranges.

Bioresearches (2009) analysed samples collected from the marina basin at Pine Harbour Marina and found a high percentage of silt and clays (~80%) in the majority of the samples. The samples were taken from areas that were subsequently dredged and disposed at the proposed site in March and April 2010. Generally, the silt and clay fraction only made up ~55% of the samples collected both before and after disposal of dredged material. This percentage was fairly consistent across the site and as well between 'pre' and 'post' disposal samples at each site. This proportion was also consistent at sites at and within 500 m of the disposal location (values are bolded in Table 4.1). Report 1 showed visible dredged material in the analysed cores at Sites H2 and H2I2, but particle size analysis did not reflect a significantly elevated silt and clay fraction as might be expected based on the results of the Bioresearches (2009) survey of the Pine Harbour Marina basin. It is likely that with the small quantity of material disposed and the locations of deposition ranging over 1000 m X 1000 m area surrounding the designated release location that the deposited material only made up a small portion, if any, of the collected cores and therefore was not enough to significantly elevate the silt and clay fractions.

4.3.2 Sediment chemistry

Heavy metal concentrations in all 6 samples were below the Effects Range-Low (ER-L) values for Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, and Zinc (Table 4.2). It was noted in Bioresearches (2009) that of these, only Arsenic concentrations exceeded the ER-L levels in tests on samples collected directly from the marina basin at Pine Harbour, but it was suggested that naturally high Arsenic levels could be expected in the area due to volcanic origins of some of the sediments there. In that case, it would be more appropriate to use the ANZECC (2000) guidelines for Arsenic rather that the unknown, possibly international source, used in the New Zealand Guidelines for the Sea Disposal of Waste (Maritime Safety Authority, 1999). In that case, levels of Arsenic in the sediment at the proposed site are significantly below the ISQG-Low level of 20 mg/kg.

Elutriation of the sediment samples similarly showed that the majority heavy metals in the sediments at all 6 sites remained bound and did not desorb into the elutriate waters (Table 4.3). The exception was Nickel, where in 3 out of the 6 samples concentration increased slightly after elutriation, 2 decreased slightly, and one increased significantly, but that was a control site sample and the validity of the measurement should be questioned. Arsenic concentrations also increased slightly after elutriation of some of the samples, but not significantly. All other metals tested remained at the same concentrations as those naturally occurring in the elutriate seawater for the 6 samples.

The bioavailability of the bound heavy metals was compared to ANZECC trigger values in Table 4.3. In all cases, the level of species protection was at least 95% even in the case of the suspect concentration of Nickel measured at the Control Site X4. Elutriate Nickel concentrations in all 6 samples exceeded the 99% species protection trigger value, but not significantly. For the cases of Chromium and Copper, the 99% protection trigger value, as well as the measured concentrations, was below the detectable limit so it is not possible to determine if the 99% protection value was exceeded. In all other cases, the 99% protection trigger values were not exceeded.

Table 4.1 Sediment grain size data for sites sampled before and after disposal of dredged material at the proposed site.

Site	%Clay (<0.0039 mm)		%Very fine silt (0.0039-0.0078 mm)		%Fine Silt (0.0078-0.0156 mm)		%Medium Silt (0.0156-0.031 mm)		%Coarse Silt (0.031-0.063 mm)		%Silt and Clay (<0.063 mm)		%Very fine sand (0.063-0.125 mm)		%Fine Sand (0.125-0.25 mm)		%Medium Sand (0.25-0.5 mm)		%Coarse Sand (0.5-1 mm)		%Very Coarse Sand (1 mm)	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
E-1	21.38	17.14	6.73	5.55	8.33	6.88	11.23	9.51	15.67	13.46	63.34	52.55	15.67	15.15	10.83	15.65	5.02	11.05	3.01	4.33	1.89	0.89
E2	5.37	18.13	8.05	5.86	12.70	7.71	18.84	10.78	20.49	14.69	65.44	57.17	16.88	16.94	12.66	14.90	4.80	6.92	0.21	2.61	0.00	1.05
E5	4.80	4.82	7.41	7.56	10.83	11.17	14.69	16.43	16.06	19.01	53.80	58.99	18.19	17.53	19.77	15.95	8.03	6.99	0.21	0.54	0.00	0.00
G1	18.76	3.93	6.58	6.52	8.18	10.68	10.55	15.67	13.75	16.69	57.83	53.48	16.61	17.24	16.15	18.79	7.82	9.21	1.20	1.28	0.00	0.00
G2	**5.41**	**4.10**	**7.89**	**6.44**	**11.58**	**10.31**	**14.77**	**15.74**	**15.02**	**18.05**	**54.68**	**54.64**	**17.09**	**17.81**	**18.19**	**17.55**	**8.17**	**8.29**	**1.40**	**1.47**	**0.48**	**0.25**
G3	6.26	3.71	9.52	5.89	14.17	8.89	18.48	13.21	18.23	14.72	66.65	46.42	15.11	15.61	12.16	20.14	5.01	13.29	0.82	3.87	0.25	0.66
H-2	21.55	4.13	6.46	6.84	7.56	10.02	10.07	13.53	14.50	15.46	60.14	49.98	15.80	15.59	13.49	17.17	8.00	12.95	2.26	4.09	0.05	0.22
H-1	4.49	15.88	7.30	5.63	11.41	6.96	16.67	9.64	17.79	13.28	57.66	51.40	14.82	15.28	13.72	16.39	8.98	12.19	3.81	4.29	1.01	0.10
H1	**17.75**	**15.64**	**5.92**	**5.63**	**7.48**	**7.34**	**9.69**	**10.03**	**12.72**	**13.46**	**53.55**	**52.10**	**16.14**	**17.97**	**17.53**	**18.28**	**9.80**	**8.00**	**2.44**	**2.29**	**0.15**	**1.02**
H2	**4.08**	**17.08**	**6.61**	**6.70**	**10.97**	**9.09**	**16.19**	**11.07**	**16.37**	**12.09**	**54.22**	**56.02**	**15.58**	**15.90**	**16.94**	**17.63**	**8.73**	**7.85**	**3.03**	**1.47**	**1.50**	**0.75**
H2G2	**-**	**4.26**	**-**	**7.06**	**-**	**10.78**	**-**	**15.75**	**-**	**17.84**	**-**	**55.69**	**-**	**16.61**	**-**	**16.92**	**-**	**9.39**	**-**	**1.37**	**-**	**0.00**
H2I2	**-**	**17.35**	**-**	**5.81**	**-**	**7.05**	**-**	**9.21**	**-**	**11.78**	**-**	**51.20**	**-**	**15.81**	**-**	**19.91**	**-**	**11.21**	**-**	**1.49**	**-**	**0.00**
H3	**3.88**	**5.35**	**5.83**	**8.08**	**8.41**	**12.41**	**11.61**	**17.87**	**12.43**	**18.48**	**42.15**	**62.18**	**16.48**	**15.37**	**24.05**	**14.39**	**14.67**	**7.30**	**2.65**	**0.77**	**0.00**	**0.00**
H5	4.59	4.78	7.38	7.52	11.17	11.75	15.64	16.97	15.89	18.04	54.67	59.05	13.70	16.07	15.28	15.49	9.96	8.10	4.23	1.28	2.15	0.00
I1	19.77	3.65	6.08	5.44	7.26	7.71	9.32	10.74	12.69	11.89	55.12	39.42	17.81	16.42	18.62	24.79	7.50	15.98	0.52	3.34	0.00	0.06
I2	**5.43**	**3.85**	**8.31**	**6.10**	**12.15**	**9.38**	**14.97**	**14.05**	**15.39**	**16.16**	**56.25**	**49.54**	**17.39**	**17.58**	**17.54**	**19.67**	**7.68**	**10.99**	**1.13**	**2.22**	**0.00**	**0.00**
I3	4.33	4.07	7.26	6.70	11.54	11.25	17.37	17.90	19.17	19.50	59.66	59.43	15.85	15.52	14.03	14.09	7.56	7.77	2.16	2.59	0.74	0.60
K-1	4.39	15.21	6.64	4.96	9.55	6.12	11.89	8.24	13.84	11.31	46.32	45.85	18.49	17.16	20.72	21.60	11.12	12.61	2.82	2.45	0.53	0.00
K2	3.52	11.79	5.97	4.14	9.35	5.77	13.81	8.53	15.05	12.07	47.70	42.29	15.86	19.30	21.05	24.72	13.50	12.37	1.89	1.05	0.00	0.00
K5	5.12	3.68	7.60	5.94	10.96	9.07	13.93	13.40	14.55	14.70	52.17	46.79	16.06	12.80	19.31	16.53	11.00	15.48	1.47	7.04	0.00	1.36
X1	-	17.70	-	5.55	-	7.17	-	9.91	-	12.08	-	52.41	-	12.72	-	17.01	-	13.95	-	3.51	-	0.04
X2	-	4.73	-	7.13	-	11.16	-	16.49	-	17.77	-	57.27	-	17.80	-	16.68	-	6.78	-	1.21	-	0.24
X3	-	21.36	-	7.47	-	9.30	-	12.01	-	15.08	-	65.21	-	15.62	-	11.93	-	4.42	-	1.32	-	1.09
X4	5.16	18.24	7.58	8.03	11.99	11.21	17.30	14.40	17.64	15.76	59.68	67.65	16.47	14.60	15.74	11.00	7.13	5.24	0.98	1.24	0.00	0.00
X5	5.03	5.41	8.62	8.51	13.69	13.14	20.18	18.94	21.70	20.14	69.22	66.14	15.99	15.46	10.12	10.03	3.44	3.38	0.92	2.68	0.31	2.30
X6	5.09	17.76	7.97	6.30	12.32	8.09	18.94	10.50	22.24	13.73	66.57	56.39	17.49	18.23	11.35	17.45	4.35	6.83	0.24	0.83	0.00	0.00
Average	8.39	10.14	7.22	6.44	10.55	9.25	14.58	13.10	16.25	15.28	56.99	54.20	16.36	16.23	16.15	17.10	8.20	9.56	1.78	2.33	0.43	0.41

*Bolded data are either at or within 500 m of the disposal location (Site H2).

Table 4.2 Sediment total recoverable metals (mg/kg of dry weight) of 6 samples collected at the proposed site following disposal of 4800 m^3 of dredged sediment (samples analysed by Hill Laboratories) and effects range values used by Maritime New Zealand.

Sample	Total Recoverable Arsenic mg/kg dry wt.		Total Recoverable Cadmium mg/kg dry wt.		Total Recoverable Chromium mg/kg dry wt.		Total Recoverable Copper mg/kg dry wt.		Total Recoverable Lead mg/kg dry wt.		Total Recoverable Mercury mg/kg dry wt.		Total Recoverable Nickel mg/kg dry wt.		Total Recoverable Zinc mg/kg dry wt.	
	ER-L 8.2**	ER-M 70**	ER-L 1.5*	ER-M 10*	ER-L 80*	ER-M 370*	ER-L 65*	ER-M 270*	ER-L 50*	ER-M 220*	ER-L 0.15*	ER-M 1*	ER-L 21*	ER-M 52*	ER-L 200*	ER-M 410*
	ISQG Low: 20*	ISQG High: 70*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E2	3.2		0.151		22		5		4		0.075		16.1		30	
G2	2.7		0.165		21		5.1		4		0.076		15.9		31	
H2	4		0.128		22		24		6.3		0.077		14.5		43	
H5	3.6		0.134		23		4.7		3.9		0.056		15.5		31	
I2	3.5		0.131		23		4.9		4.2		0.067		15.6		31	
X4	2.5		0.149		21		5.4		4.3		0.056		16.3		31	
Detection Limit	0.5		0.03		0.25		0.25		0.1		0.1		0.5		0.5	

*Effects Range Low and Medium (ER-L & ER-M) and ISQG-Low & High values taken from ANZECC interim sediment quality guidelines (ANZECC, 2000).
**ER-L & ER-M values for Arsenic taken from Maritime Safety Authority (1999) (original source not cited).

Table 4.3 Sediment elutriation data of 6 samples collected at the proposed site following disposal of 4800 m^3 of dredged sediment (samples analysed by Hill Laboratories) and ANZECC trigger values.

	Arsenic μ/L	**Cadmium μ/L**	**Chromium μ/L**	**Copper μ/L**	**Lead μ/L**	**Mercury μ/L**	**Nickel μ/L**	**Zinc μ/L**
Level of protection (% species)	**ANZECC Trigger values for marine water (μg/L)**							
99	ID	0.7	0.14	0.3	2.2	0.1	7	7
95	ID	5.5	4.4	1.3	4.4	0.4	70	15
90	ID	14	20	3	6.6	0.7	200	23
80	ID	36	85	8	12	1.4	560	43
Sample								
Elutriate (Seawater)	<4.2	<0.21	<1.1	<1.1	<1.1	<0.08	9.2	<4.2
E2	4.7	0.21	<1.1	<1.1	<1.1	<0.08	8.9	<4.2
G2	<4.2	<0.21	<1.1	<1.1	<1.1	<0.08	10.8	<4.2
H2	<4.2	<0.21	<1.1	<1.1	<1.1	<0.08	10.1	<4.2
H5	4.8	<0.21	<1.1	<1.1	<1.1	<0.08	8.7	<4.2
I2	<4.2	<0.21	<1.1	<1.1	<1.1	<0.08	10.1	<4.2
X4	6.1	0.22	<1.1	<1.1	<1.1	<0.08	65	<4.2
Detection limit	4.2	0.21	1.1	1.1	1.1	0.08	6.3	4.2

*Trigger values taken from ANZECC (2000) water quality guidelines for toxicants.
ID=insufficient data to derive a reliable trigger value.

Total petroleum hydrocarbons (TPH) measured in the 6 samples collected from the proposed site following disposal of ~4800 m^3 of dredged material are shown in Table 4.4. In all cases, the measured values were lower than those reported by Bioresearches (2009) on the samples collected directly from the marina basin at Pine Harbour. There are no TPH guidelines listed in the New Zealand Guidelines for Sea Disposal of Waste (Maritime Safety Authority (1999), but as the levels measured at the location of dredged material deposition (Site H2) are the same as locations where material would be less likely to have deposited, there does not appear to be a concern with TPH levels at the proposed site. TPH levels would be expected to build up over time if the material disposed at a site had high levels, but as TPH levels are generally low at Pine Harbour (Bioresearches, 2009), it would not be expected to become a problem for ongoing use of the site.

Table 4.4 Sediment total petroleum hydrocarbons (TPH). TPH analysed by Hill Laboratories.

Sample	C7-C9 (mg/kg dry wt.)	C10-C14 (mg/kg dry wt.)	C15-C36 (mg/kg dry wt.)	Total hydrocarbons (C7-C36) (mg/kg dry wt.)
E2	<15	<30	<60	<100
G2	<15	<30	<60	<110
H2	<15	<30	<60	<110
H5	<15	<30	<60	<100
I2	<14	<30	<60	<100
X4	<17	<40	<70	<120

4.3.3 Geomechanical strength and dredged material fate

Horizontal and vertical variations in shear strength of the sediment at locations across the disposal site were small ranging from ~0.6 – 1.6 kPa following disposal of the first two loads of dredged material. Low shear strength values were expected as both the naturally occurring sediment as well as the disposed sediment was very soft (i.e. high proportions of silts and clays). Interpreted shear strengths matched reasonably well with lab shear vane measurements on cores collected from several *Nimrod* deployment positions (Flaim *et al*., *in press*). Despite the generally low shear strengths, four different shear strength profile types were identified, the features of which may be associated with deposition of dredged material, but also may be associated with natural geomechanical sediment processes. The four types are described as follows (note: the first several centimetres of each profile are ignored due to spurious interpreted strengths, artefacts of the interpretation method (Flaim *et al.*, *in press*).

i. Type A: The deceleration of the probe increases approximately linearly with depth. Shear strength is mostly uniform along the depth profile (occasionally a slight increase with depth, but similar to deceleration, the increase is approximately linear) (e.g. Figure 4.4).

ii. Type B: The deceleration profile takes a “concave-down” shape with an “S”-shaped strength profile (when considering the entire profile). Below

~5 cm and above the deepest 1-2 cm of the profile, the shear strength increases more dramatically with depth (e.g. Figure 4.5).

iii. Type C: The deceleration increases sharply at a certain depth reflected by a “kink” in the profile. A sharp increase in the strength can likewise be identified at that depth in the profile (e.g. Figure 4.6).

iv. Type D: The deceleration profile takes a “concave-up” shape with an uncharacteristic strength pattern (e.g. Figure 4.7). Although less pronounced in Figure 4.7a, typically, the strength appears to be highest in the upper part of the profile (even well below upper 5 cm where the highest values are encountered right after the impact).

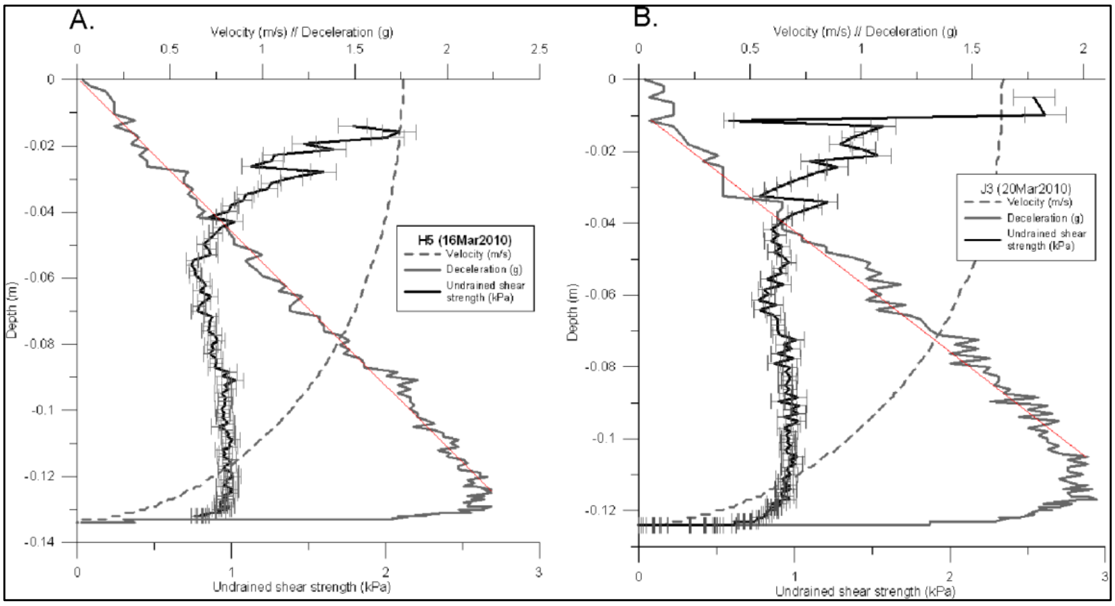


Figure 4.4 “Type A” profiles from *Nimrod* deployments on the A) Mar16 & B) Mar 20 2010.

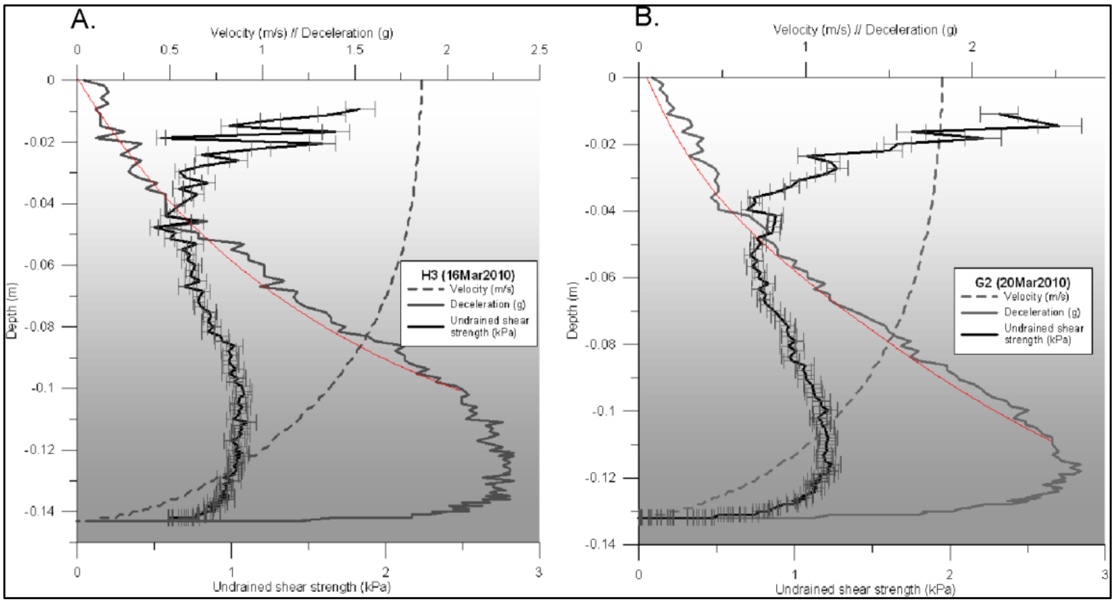


Figure 4.5 “Type B” profiles from *Nimrod* deployments on the A) Mar16 & B) Mar 20 2010.

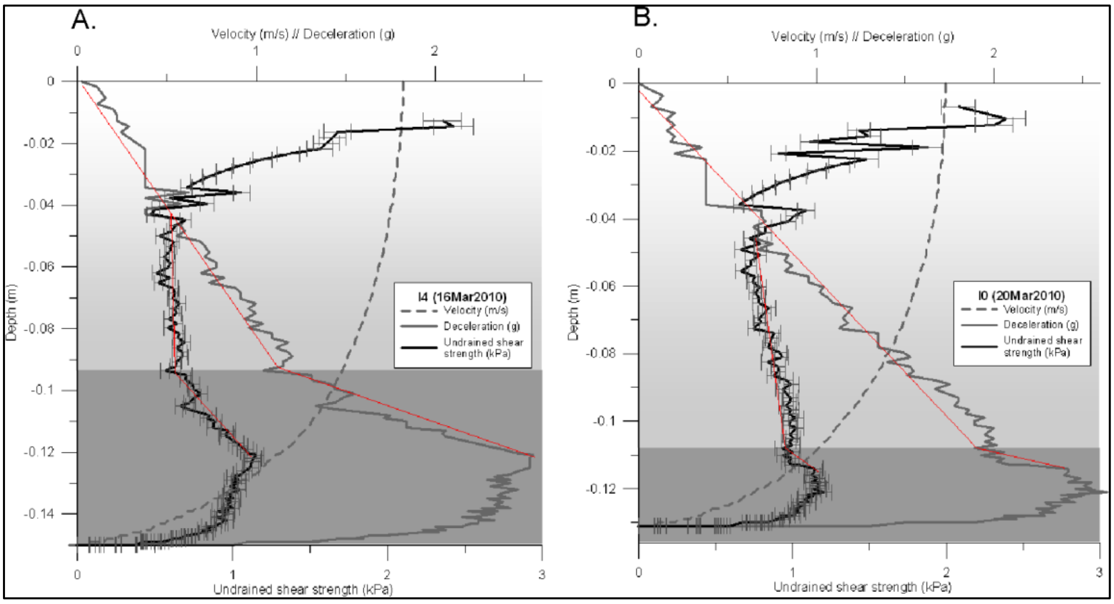


Figure 4.6 "Type C" profiles from *Nimrod* deployments on the A) Mar16 & B) Mar 20 2010.

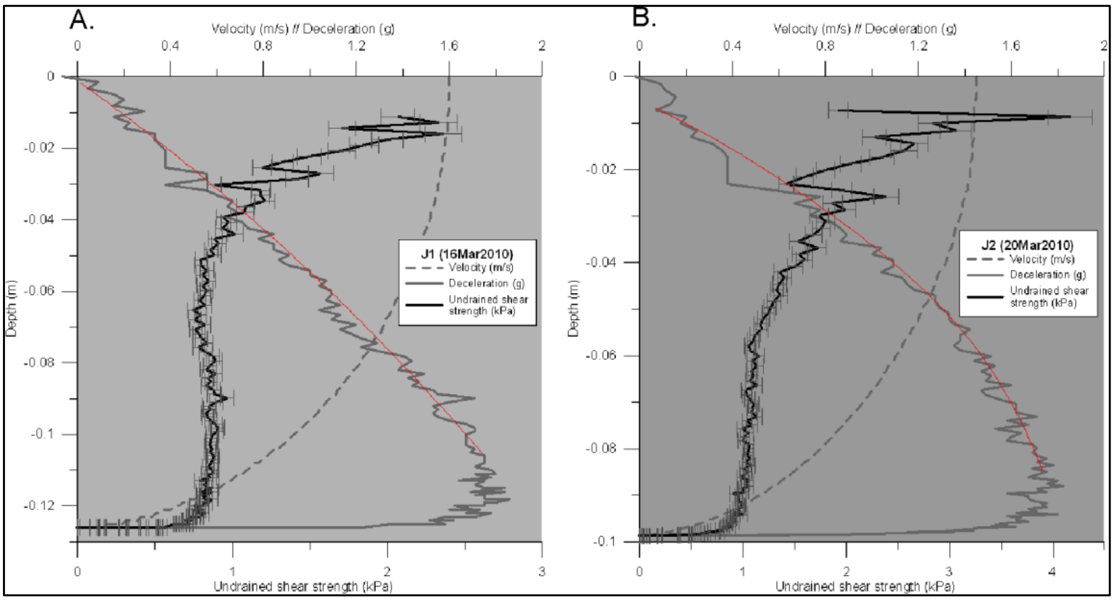


Figure 4.7 "Type D" profiles from *Nimrod* deployments on the A) Mar16 & B) Mar 20 2010.

All of the positions visited during the baseline *Nimrod* survey showed either Type A or B profiles whereas following disposal of the first two loads of material, Types C and D were also observed. The spatial arrangement of the profile types following disposal of loads 1 and 2 are shown in Figure 4.8. At each deployment location, the profile type changed between the two disposals, so it is possible that disposal processes may have been an influence, but there are several plausible theories even within the idea that disposal mechanics were the driving factor for shaping the strength profiles. For instance, intuitively, at the point of impact of the main component of the dredged material, one might expect higher shear strengths at the surface of the profile reflecting the dense blocks that descend rapidly through the water column within minutes after release. However, as observed at Site H2 (the supposed point of impact for the disposed material) in the underwater video (see Report 6), the dense blocks were scattered and interspersed with areas where the seafloor appeared smooth. In those areas, the smooth material could also represent deposited material, but not the dense blocky fraction. In the case of Pine Harbour Marina, the dredged material is soft made of silt and clay, so the smooth areas might be expected to have a similar or possibly lower shear strength than that of the underlying sediment. Furthermore, typical disposal mechanics include a turbidity current phase which is induced by the impact of the main component with the seafloor. The energy of this current can be initially quite high and capable of entraining the naturally occurring sediments, causing mixing with the disposed material and dispersion of both followed by subsequent deposition some distance from the point of impact. The actual point of impact of loads 1 and 2 are undetermined, but more than likely these two loads did not deposit directly at the coordinates of Site H2 and in fact, the MBES backscatter map described in Report 2 did not show an area of higher backscatter intensity (indicating dredged material) directly in the centre of the site, rather these patches form a 100 to 200 m radius around the centre. Therefore, it is very possible that the *Nimrod* deployments at Site H2 following disposal of loads one and 2 did not penetrate through the deposited main component of the two loads.

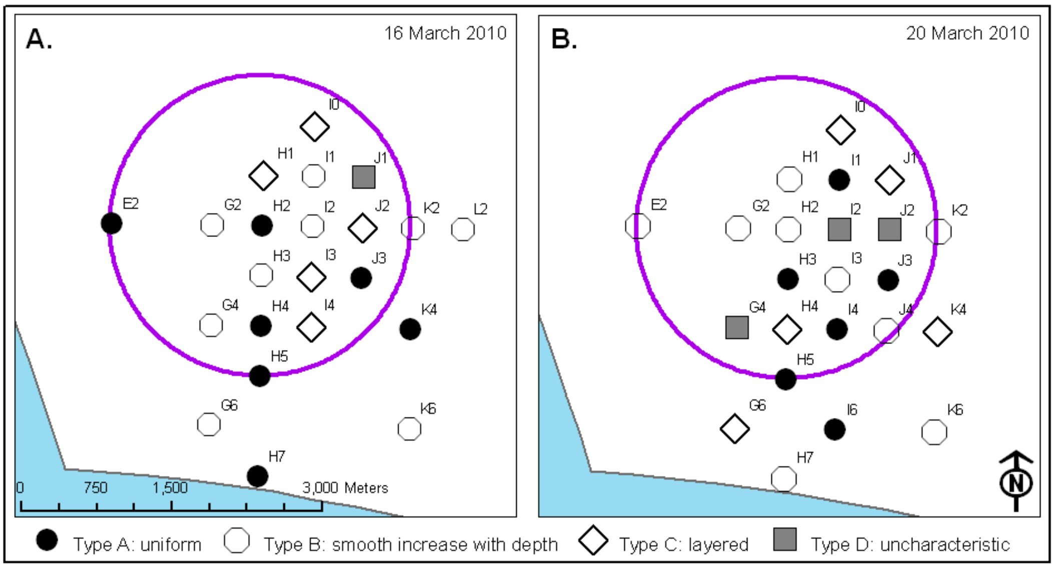


Figure 4.8 Sediment strength characteristics indicated from interpretations of Nimrod deployments on A). 16 March 2010 and B). 20 March 2010 across the proposed disposal site.

After disposal 1 on March 16, the profile type observed at Site H2 was Type A with a uniform sediment strength with depth suggesting that mixing and entrainment by the turbidity current may have influenced the profile development. Following disposal of load 2 the strength profile was found to be a Type B with a smooth increase in shear strength of the sediment with depth. Whether in this case, the March 20 profile at Site H2 was influenced by the disposal of material on the same day, or whether this profile reflects settling of mixed material from the disposal on March 16 is unknown. When considering the strength profiles at other deployment sites, contradictions to these interpretations can be identified. Furthermore, due to the relatively small amount of material disposed in loads 1 and 2, it is not unlikely that the variation in profile types across the site and between surveys may be attributed not to disposal processes, but naturally occurring geomechanical processes such as entrainment by local currents, settling/consolidation, and/or biological infaunal activity.

For future disposal site monitoring, a dynamic penetrometer such as *Nimrod* may in fact be a useful tool for determining dredged material fate, but in this case timing conflicts prevented the collection of the full post-disposal dataset. Therefore, reliable conclusions on the fate of the dredged material after disposal of loads 1 and 2 cannot be made.

4.4 CONCLUSIONS

i. Sediment texture ranged from clay (<0.0039 mm) to very coarse sand (1 mm) both before and after disposal of ~4800 m^3 dredged material at all sites sampled across the proposed site. Approximately 55% of each sample was silt and clay. Disposal of dredged material did not appear to significantly change the composition of the sediment size classes at the site.

ii. Sediment heavy metal concentrations in each of the 6 samples tested were well below the ER-L value set by the ANZECC interim sediment quality guidelines and referred to by Maritime New Zealand in the New Zealand Guidelines for Sea Disposal of Waste (ANZECC, 2000; Maritime Safety Authority, 1999).

iii. Elutriate heavy metal concentrations did not exceed the 95% species protection level trigger value in all cases. Only Nickel concentrations in the elutriate water of each of the 6 samples conclusively exceeded the 99% species protection level trigger value. The 99% species protection level trigger value for Chromium and Copper as well, as the sample concentrations of these metals in all cases were below the detection limits, so it is inconclusive whether the 99% levels were exceeded.

iv. TPH levels in each of the 6 samples were lower than those collected directly from the marina basin at Pine Harbour. TPH levels after disposal of ~4800 m^3 at the proposed site do not appear to be an environmental concern.

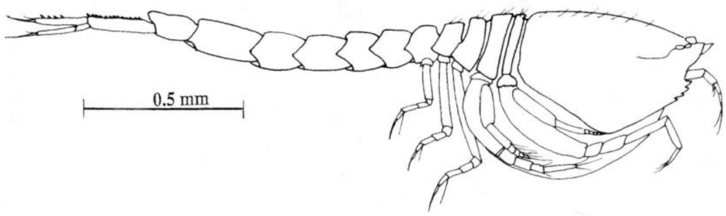
v. Based on geomechanical shear strength data derived from *Nimrod* dynamic penetrometer measurements after disposal of loads 1 and 2, dredged material fate is inconclusive. However, it does appear that for future monitoring and after disposal of a larger quantity of dredged material, dynamic penetrometers may be a useful complement to other post-disposal monitoring techniques such as MBES.

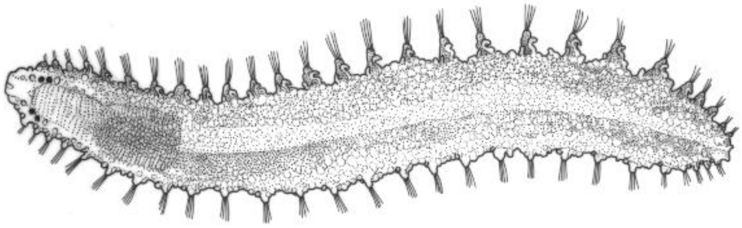
AUCKLAND MARINE DISPOSAL GROUND

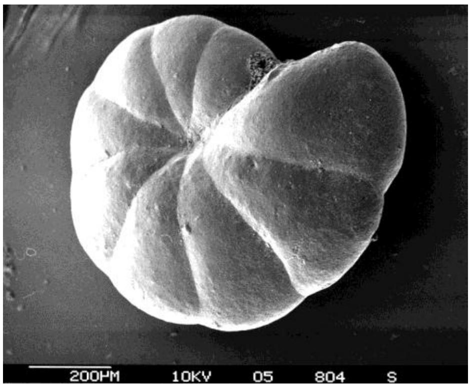
MONITORING SERIES

REPORT 5 BIOLOGICAL ASSESSMENT

February 2011







5.1 BACKGROUND

A biological assessment of the Auckland Marine Disposal Ground 25 km east of Great Barrier Island was undertaken both before and after disposal of ~4800 m^3 of dredged sediment from Pine Harbour Marina. The focus was primarily on benthic infauna though epibenthic as well as pelagic species were also considered.

Data collected prior to disposal of dredged material provides a baseline for the composition and abundance of species occurring at the site. This data can be compared to that collected following post-disposal, however, it should be cautioned that species composition and abundances are seasonally variable and apparent changes following disposal cannot necessarily be attributed the presence or absence of dredged material.

5.2 METHODOLOGY

5.2.1 Benthic infauna

In June 2009 and January 2010 benthic cores were collected from locations across the disposal site as well as at nearby control sites (Figure 5.1). In June 2010, following disposal of dredged material, cores were again retrieved at locations shown in Figure 5.1. Generally, two cores were collected at each position; one for sediment analysis (see Report 4) and the other for benthic infaunal assessment. For details on the sampling procedure please refer to Report 1.

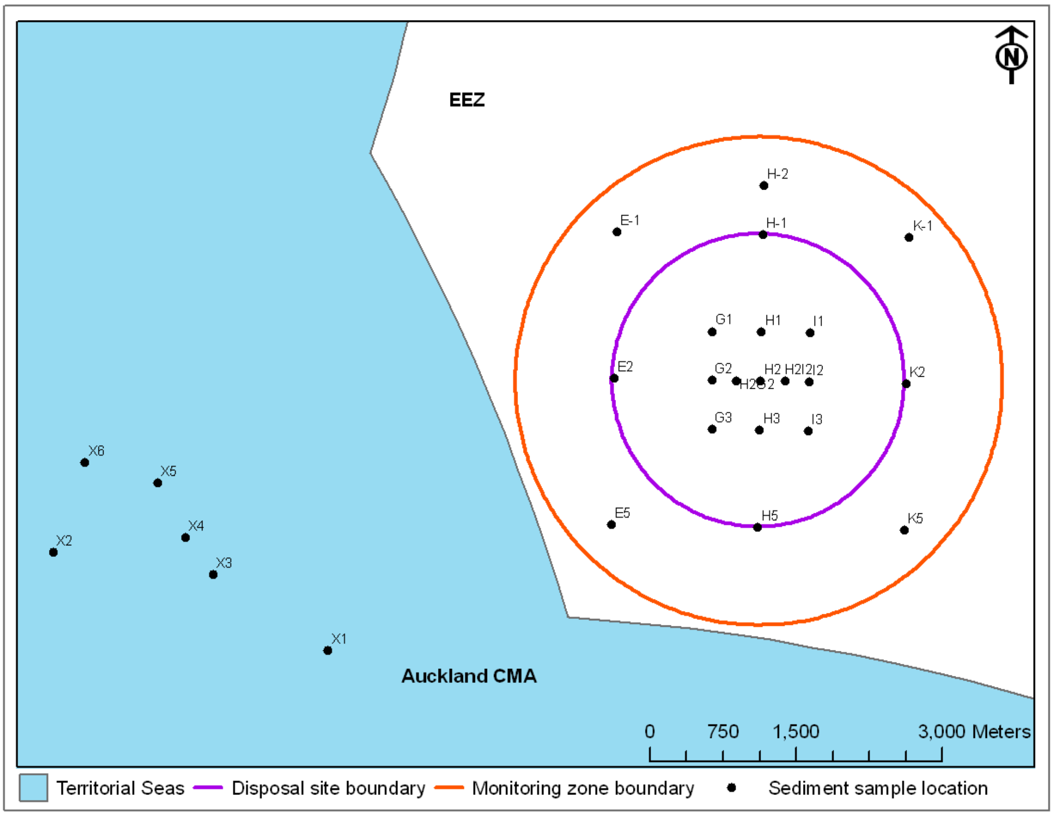


Figure 5.1 Map location of the proposed disposal site, monitoring zone, Territorial Sea/EEZ boundary, and locations where sediment cores were collected before and after disposal of 4800 m3 of dredged material.

As soon as the cores were brought out of the water, the samples were extruded and placed in labelled ‘ziplock’ bags. Samples were stored on ice while onboard and after the survey was completed, the samples were frozen for long-term storage until further assessment was possible.

Taxonomic identification was contracted to Bioresearches. Frozen samples were allowed to defrost in a bath of 10% formalin for 48 hours. The samples were then gently washed with tap water through a 0.5 mm sieve to remove fine sediment. The retained material from each sample was preserved in 70% isopropyl alcohol. Organisms from each sample were then sorted out and placed into a labelled vile of 70% isopropyl alcohol. Taxonomic identification was then undertaken on each sample to the lowest possible level.

5.2.2 Benthic epifauna and pelagic fauna

Video footage was undertaken in July 2010 following disposal of dredged material to assess the presence of fish and crayfish and to gain a photographic record of the site. No future video footage is recommended or considered necessary.

The camera used was stationary, but tilt and panning capabilities allowed for a field of vision range from almost a top view (bird’s eye view) of the seabed to a profile view of approximately one meter above the seafloor when tilted up to its maximum extent. From these viewpoints it was possible to examine the epibenthic and pelagic environments (at least that within 1 meter of the bed). Refer to Report 6 for a detailed description of the camera apparatus used and the locations filmed.

Once the camera reached the seabed, panning was undertaken systematically for several minutes exploring the full viewing range at each location.

5.3 RESULTS

Table 5.1 shows benthic biota counts for each species/taxa present in samples collected prior to disposal of dredged material at the site. Table 5.2 shows benthic biota counts for each species/taxa present in samples collected after disposal of dredged material at the site. Species/taxa composition of the site, based on samples collected varies somewhat between the two sampling periods. Out of 49 total species/taxa identified at the site, 21 were present in both the pre-and post-disposal samples.

Table 5.3 shows the total number of species/taxa and total number of individuals in each sample collected. There does not appear to be any significant trend(s) between the two sampling periods. However, the total number of individuals collected before and after disposal of dredged material was 1142 and 1098, respectively. At site H2, total number of individuals decreased from 73 to 44 and total number of species/taxa decreased from 11 to 7. It is possible that the decrease is due to deposition of dredged material, but seasonal, as well local, variation would also be likely explanations. Ultimately, a decrease in species abundance and diversity is an anticipated effect of deposition of dredged material, so these findings are not unexpected. It should be mentioned though that at some of the sites near the centre disposal coordinates, there was an increase in species abundance and diversity following disposal.

The majority of organisms collected in each sample were of the phylum Foraminifera. Forams, very small (in the order of 1 mm) amoeboid protists, would likely dominate in abundance in any sample from the area. It should be noted that the small sample size (70 mm diameter core, where most organisms would occur in the top 5-10 cm) might introduce a bias towards organisms of a smaller size without significant space requirements. However, the ~20 samples collected over a large area of the site are likely to be sufficiently representative of the types of organisms that are present there.

In general, the organisms identified were similar to those identified in another study in a similar area undertaken by the Department of Conservation (DOC) in 2002 (Sivaguru and Grace, 2002). In that study, 4 sample sites at depths greater than 120 m were described. The seafloor at the 4 sites was silty mud, similar to that at the disposal site therefore species composition would be expected to be comparable. Indeed, many of the species/taxa identified at the disposal site were present in the 2002 study. However, the species composition is less diverse at the disposal site most likely because it is located further southeast and in water somewhat deeper than that of the previous study.

Underwater video footage did not record any pelagic organisms and very few epibenthic organisms were observed. One sessile organism, most likely a Sea Pen (Order Pennatulacea), was observed in the footage recorded at Site G2 (Figure 5.2), but other than that, the only evidence of epibenthic activity were some tracks in the seafloor which along with relatively common worm burrows, contributed to the ‘micro-relief’ described in Report 6.

Figure 5.2 A sessile benthic invertebrate (most likely a Sea Pen-Order Pennatulacea) recorded in underwater footage at location G2 of the disposal site in June 2010.

Table 5.1Biota count of benthic core samples collected in June 2009 and January 2010 prior to disposal of dredged material at the site.

	Pre E-1	Pre E2	Pre E5	Pre G1	Pre G2	Pre G3	Pre H1	Pre H-1	Pre H2	Pre H-2	Pre H3	Pre H5	Pre I1	Pre I2	Pre I3	Pre K-1	Pre K2	Pre K5	Pre X1	Pre X2	Pre X3
PHYLUM ANNELIDA																					
CLASS POLYCHAETA																					
Agalophamus ?macroura			1		1				1							1					
Cirratulidae												1									
Eunice sp.	1																	1			
Flabelligeridae																		1			
Lumbrinereis sp.																					1
Pectinaria australis											tube only										
Prionospio sp.												1						1			
Spionidae			1			1			1	1	1							1		1	3
Indet polychaeta (damaged/pieces)												1						2	2		
PHYLUM NEMERTEA																					
Nemertian																	1				
PHYLUM MOLLUSCA																					
CLASS BIVALVIA																					
?Dosinia sp.																1					
Nucula nitidula									1				1								
Nucula nitidulaformis				1																	
CLASS SCAPHOPODA																					
Dentalium (Antalis) nanum		2				1							2		3			1			
PHYLUM ARTHROPODA																					
CLASS CRUSTACEA																					
ORDER AMPHIPODA																					
Atylidae														1							
Phoxocephalidae sp. 1													1								1
ORDER OSTRACODA																					
Ostracoda sp.					1																
ORDER TANAIDACEA																					
Tanaid sp.								1													
PHYLUM COELENTERATA																					
CLASS ANTHOZOA																					
Edwardsia sp.															1						
PHYLUM FORAMINIFERA *																					
CLASS FORAMINIFERA																					

ORDER ASTORHIZIDA																					
Aggulinate tubes, broken, *?Rhabdammina*										2											
ORDER LITUOLIDA																					
Ammodiscus spp													1		1						
ORDER TEXTULARIIDA																					
Aggerostramen sp.			1			1		1	1			1					1	3		1	
ORDER MILIODIDA																					
Nummuloculina contraria				1							1		1		1		1				
Pyrogo spp		1	1	5		2		1	4		3	1	4	1	3	1		1	1	1	1
Quinqueloculina suborbicularis			1	1	1				3												
Trioculina insignis	1	1		1					1	1			1			1	1		1		5
ORDER LAGENIDA																					
Lenticulina spp	5	8	10	11	11	1	10	11	15	7	15	5	13	7	8	12	2	10	4	2	12
Nodosaria intermittens/vertebralis		1	1	1								1				1					
ORDER ROTALIIDA																					
Cibicidoides sp 1	27	20	9	54	14	6	32	59	34	36	32	7	60	38	37	144	38	32	3	4	1
? Cibicidoides sp 2	6	5	3	12	3		2	9	8	6	6	2	12	8		11	8	2			4
Indet. Foraminifera - spine like	2	4	1	3	5		1	6	4	1	2		2		5	1	6	3	1	1	

* = No attempt has been made to distinguish live from dead specimens.

Table 5.2Biota count of benthic core samples collected in June 2010 following disposal of dredged material at the site.

	Post E-1	Post E2	Post E5	Post G1	Post G2	Post G3	Post H1	Post H-1	Post H2	Post H-2	Post H2/G2	Post H2/I2	Post H3	Post H5	Post I1	Post I2	Post I3	Post K-1	Post K2	Post K5	Post X1	Post X2	Post X3	Post X4	Post X5	Post X6
PHYLUM ANNELIDA																										
CLASS POLYCHAETA																										
Agalophamus ?macroura		?1							1		1			1												
Aricidea sp						1																				
Capitellidae																						3				
Cirratulidae						1																				1
Lumbrinereis sp.												1									1					1
Marphysa sp.		1		1			1										1									
Maldanidae		1									1		1		1										1	1
Orbinia sp.																				1						
Spionidae						1				2													1			
Syllidae						1																			1	
Indet polychaeta (damaged/pieces)			1					1	1	2		1						2	1		1	1	1			1
PHYLUM NEMERTEA																										

Nemertian							2			1																
PHYLUM MOLLUSCA																										
CLASS BIVALVIA																										
Nucula nitidula		1					1			1			1													
Spectamen plicatulum																			1							
CLASS SCAPHOPODA																										
Dentalium (Antalis) nanum			1					1				1					1									
PHYLUM ARTHROPODA																										
CLASS CRUSTACEA																										
ORDER AMPHIPODA																										
Lysianassidae		1															1								1	
Phoxocephalidae sp. 2																									1	
Indet. Amphipod species (damaged)		1																								
ORDER DECAPODA																										
Lyreidus tridentatus			1																							
ORDER CUMACEA																										
Cumacean sp.																1										
ORDER OSTRACODA																										
Ostracoda sp.																			1							
ORDER TANAIDACEA																										
Tanaid sp.																									1	
PHYLUM ECHINODERMATA																										
CLASS OPHIUROIDEA																										
Amphiura sp.																										1
PHYLUM PORIFERA																										
CLASS DEMOSPONGIAE																										
Indet sponge - orange/tan						1																				
PHYLUM FORAMINIFERA *																										
CLASS FORAMINIFERA																										
ORDER LITUOLIDA																										
Ammodiscus spp					2						1			1		1	1	1	1							
Cribrostomoides / Haplophramoides										1																
ORDER TEXTULARIIDA																										
Aggerostramen sp.		2				3		1			1	1	1				1			1						
Textularia stricta		1				1																				
ORDER MILIODIDA																										
Nummuloculina contraria				2						1	1	1	2											2		

Pyrogo spp	1	3			2		1	1								1		2	2		3	1				2
Quinqueloculina suborbicularis								1											1							1
Trioculina insignis		2	1				2		1				1	3		2	2					1				
Indet. Miliodida foraminifera						1																				
ORDER LAGENIDA																										
Lenticulina spp	4	10	4	6	7	8	17	10	9	17	8	18	18	6	4	21	10	7	10	6	3	3	3	1	6	2
Nodosaria intermittens/vertebralis		1				1		1		1									1	2		1				
ORDER ROTALIIDA																										
Cibicidoides sp 1	15	34	19	29	18	62	59	21	26	53	31	67	32	12	26	55	23	81	43	28	3	1	3	2	3	
? Cibicidoides sp 2	2	10	2	3	3	3	11	1	5	8	2	6	7	8	7	11	2	10	4	5		1			1	1
Indet. Foraminifera - spine like	2			2	1	5	4	5	1	5	1		2		2	4	1	3	2	1		1				1

* = No attempt has been made to distinguish live from dead specimens.

Table 5.3Total number of species and individuals for each location before and after disposal of dredged material.

Location	Time	Total number of species/taxa	Total number of individuals		Location	Time	Total number of species/taxa	Total number of individuals
E-1	Pre	6	42		H5	Pre	9	20
	Post	5	24			Post	6	31
E2	Pre	8	42		I1	Pre	11	98
	Post	13	68			Post	5	40
E5	Pre	10	29		I2	Pre	5	55
	Post	7	29			Post	8	96
G1	Pre	10	90		I3	Pre	8	59
	Post	6	43			Post	10	43
G2	Pre	7	36		K-1	Pre	9	173
	Post	6	33			Post	7	106
G3	Pre	6	12		K2	Pre	8	58
	Post	13	89			Post	11	67
H1	Pre	4	45		K5	Pre	12	58
	Post	9	98			Post	7	44
H-1	Pre	7	88		X1	Pre	6	12
	Post	10	43			Post	5	11
H2	Pre	11	73		X2	Pre	6	10
	Post	7	44			Post	9	13
H-2	Pre	7	54		X3	Pre	8	28
	Post	11	92			Post	4	8
H2/G2	Pre	-	-		X4	Pre	-	-
	Post	9	47			Post	3	5
H2/I2	Pre	-	-		X5	Pre	-	-
	Post	8	96			Post	8	15
H3	Pre	7	60		X6	Pre	-	-
	Post	9	65			Post	10	12

5.4 CONCLUSIONS

Benthic biota present at the site appears to be typical of the deeper shelf regions east of Great Barrier Island. Species composition and abundance at the site varied somewhat between the two sampling surveys, but it is not likely that the addition of dredged material had a great influence. Trends in this regard would only become more obvious after larger quantities of material were disposed at the site. Most likely, the differences observed can be attributed to seasonal and local variation.

Underwater video showed that the seafloor is virtually barren, even in areas far from the disposal release coordinates, suggesting that there were very few epibenthic organisms present at the site at the time of the video survey. Similarly, no pelagic organisms were observed in the recorded footage which showed the water column approximately 1 metre off the seafloor.

The site does not appear to be an ecological hotspot and even though the benthic community will be affected if the site is used in the long-term for disposal of dredged material, the impact can be expected to be negligible outside the site boundaries.

5.4.1 Future Recommendations

Benthic biota sampling- A larger sampling device such as a box dredge should be used in future surveys of benthic biota as it would provide a more representative sample. However, once the sample is collected, the device should retain it effectively during the relatively long ascent to the surface. The ‘SHIPEK’ grab sampler used in preliminary surveys at the site collected a larger sample than that of the gravity corer, but during the ascent much of the sample was washed out.

Additionally, samples should be sieved immediately or as soon as possible after retrieval on board. If this step cannot be undertaken onboard, it should be done within 12 hours after retrieval. Material retained in the 0.5 mm sieve should then be preserved in labelled containers with a 10% formalin solution for at least 24 to 48 hours before being transferred to a 70% isopropyl alcohol solution for storage prior to sorting and identification. Immediate sieving and preservation of the organisms prevents degradation and damage to the structure of the organisms, which in turn makes taxonomic identification a more accurate process.

Underwater video- Further video footage would most likely be redundant, but should it be deemed necessary, some improvements to the methodology should be made. Video footage for the purposes of assessing the presence of epibenthic and pelagic organisms would provide more comprehensive information if the camera was movable; possibly side-facing on a towed sled, where transects across the site could be captured. However, the significant water depths of the site might make it logistically difficult. Alternatively, a downward-facing camera with a wide field of view could be suspended above the seafloor (within a couple metres) and towed in transects across the site. This method would allow for observing any epibenthic organisms as well as any pelagic species within two metres of the bed, without stirring up the sediment and obscuring the view.

AUCKLAND MARINE DISPOSAL GROUND

MONITORING SERIES

REPORT 6 PLUME IMAGERY AND UNDERWATER VIDEO

February 2011

6.1 BACKGROUND

Both during and after the test disposal operations at the site, video footage and photographs were recorded. The aim of attaining the imagery was to visually ground truth both the location of the plume arising from disposal of dredged material as well as the ultimate fate of the material on the seafloor. This report will focus on observations from relevant freeze frame images of video footage as well as aerial photographs captured at the disposal site.

Disposal operations were initiated at the site on March 14 2010. The 9 loads of dredged material from Pine Harbour Marina were disposed at the centre of the site throughout the months of March and April 2010. Plume survey monitoring was undertaken on loads released at the site on April 10, 15, 21, and 25 2010. Prior to these surveys, during the release of the second load of material on March 20 2010, the surface plume arising from disposal was observed from air and sea.

On April 25 2010, during Survey 4 continuous footage of the main survey vessel echosounder was recorded by filming the monitor using a handheld video recorder. It was noted during previous surveys that the images of the disposed material displayed quite clearly with this device as the vessel passed over the plume. Even though the device was not capable of recording quantitative data on the sound intensity related to the plume such as what was possible using the ADCP, typically the imagery of the vessel sounder was clearer than that of the ADCP. This was particularly true immediately following release when the main very dense component of the material descended rapidly to the seafloor. At those density levels, the ADCP system was not capable of recording data, so it is useful to refer to the sounder video for the critical first minutes after release.

Following the completion of disposal operations, after the release of approximately 4800 m^3 of dredged material at the site during March and April 2010, underwater video of the seafloor was recorded at established sample locations and control sites. This video was recorded on July 26 2010, several months after the last load of material was disposed at the site.

6.2 SURFACE PLUME: AERIAL PHOTOGRAPHS

Prior to disposal of the second load of material at the site on March 20 2010, observation teams arrived at the site via vessel and helicopter. After the load of material had been released from the split hull hopper, aerial photographs were taken continually as the helicopter circled the plume. Photographs were later correlated to time using notes made aboard the helicopter. Figures 6.1-6.7 show the spatial extent of the surface plume 3, 6, 18, 20, and 34 minutes after release. On this day, the tug and towed hopper travelled from southwest to northeast and after passing over the agreed upon disposal coordinates the split bottom doors of the hopper were set in motion to open. Material dropped out of the hopper over approximately 150 m as the tug travelled at several knots in the northeast direction. As a result of this release procedure, the surface plume took on a very elongated and narrow shape. After all the material had exited the hopper, the tug made a u-turn and headed southwest in the direction of Auckland (Figures 6.1 and 6.2).

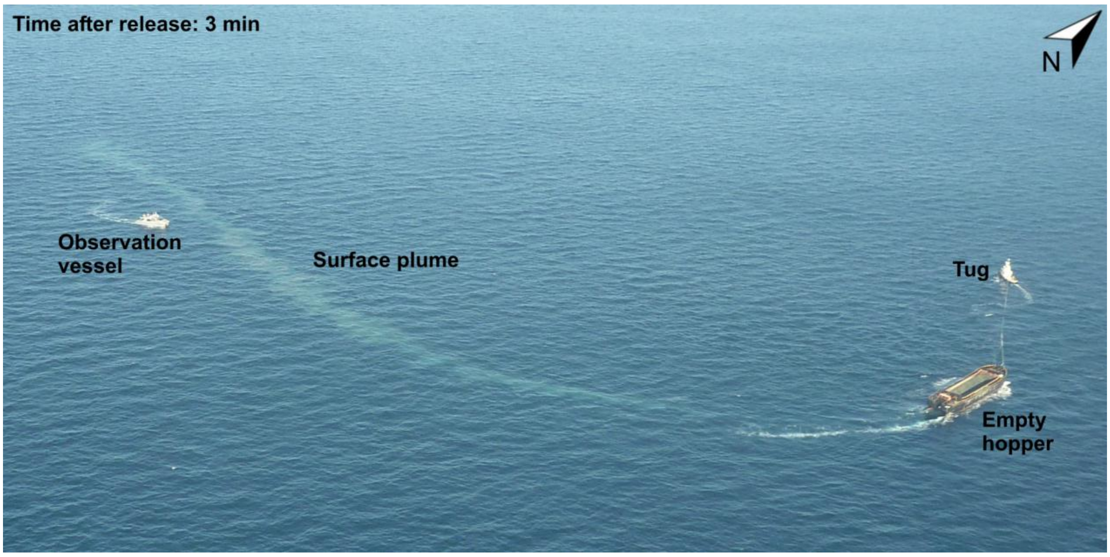


Figure 6.1Aerial photo of surface plume 3 minutes after disposal of dredged material at the site on March 20 2010 (photo: Simon Male).

Figure 6.2Aerial photo of surface plume 6 minutes after disposal of dredged material at the site on March 20 2010 (photo: Simon Male).

The visibility of the plume was dependant on both its concentration and the glare from the sun on the water surface. In the photo taken after 18 min, the plume appeared only faintly and already looked much dispersed (Figure 6.5). However, Figure 6.6 shows that while having clearly undergone dilution through dispersion compared to photos taken earlier, the plume was still quite visible after 20 min.

The length of the plume was estimated in photographs that were taken close to overhead ('bird's-eye-view'), the reason being that the perspective of the photograph skews the scale when the view is from a low side angle. A reasonably accurate scale was applied to Figures 6.6 and 6.7 using the known length of the observation vessel (16.8 m) in the photograph. From this estimate, the plume in this instance was approximately 150 m long from southwest to northeast and approximately 20 m in width.

After 34 min, the surface plume was still visible, but dilution and dispersion were apparent. This timing corresponds with data recorded during the 4 plume monitoring surveys which showed that plume concentrations did not decrease to background levels until approximately 60 minutes after disposal on each occasion (Report 3).

Figure 6.3 Aerial photo of surface plume 6 minutes after disposal of dredged material at the site on March 20 2010 (photo: Terry Healy).

Figure 6.4 Aerial photo of surface plume 6 minutes after disposal of dredged material at the site on March 20 2010 (photo: Terry Healy).

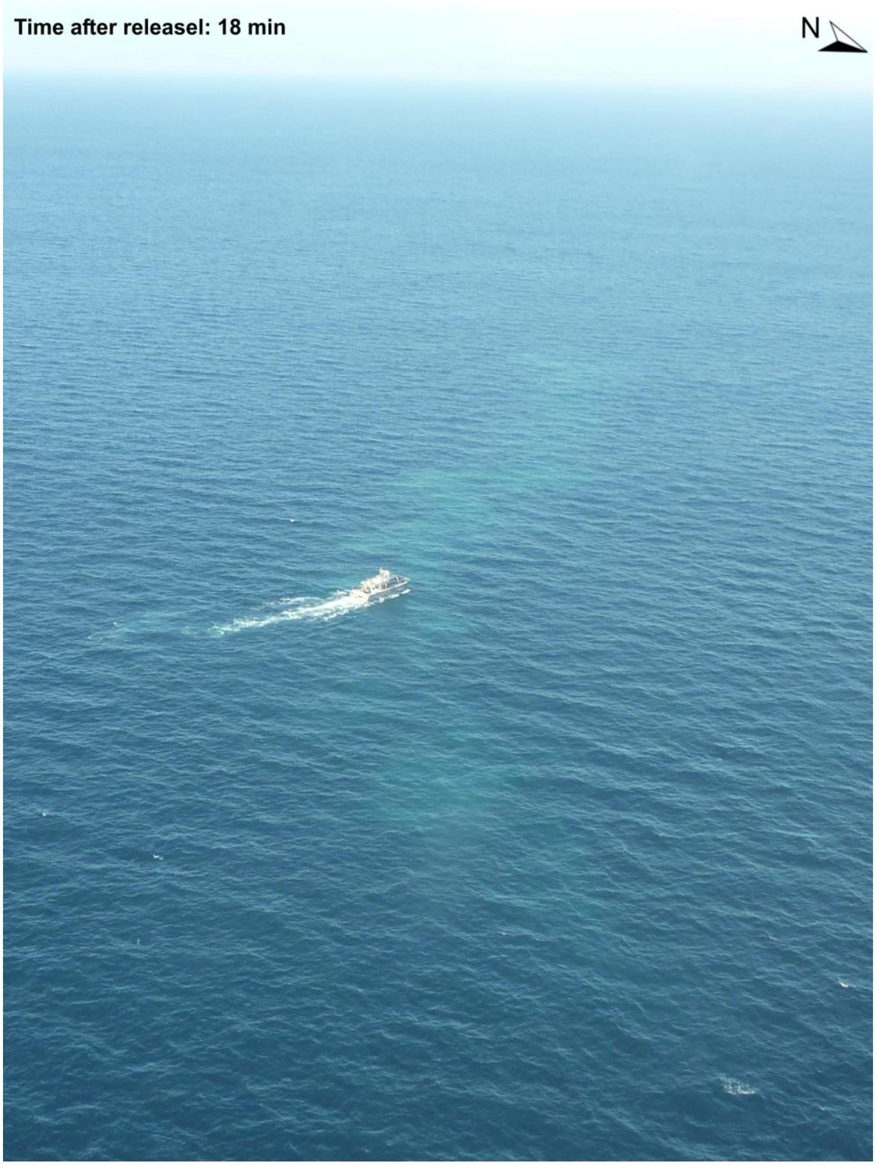


Figure 6.5 Aerial photo of surface plume 18 minutes after disposal of dredged material at the site on March 20 2010 (photo: Simon Male).

Figure 6.6 Aerial photo of surface plume 20 minutes after disposal of dredged material at the site on March 20 2010 (photo: Terry Healy).

Figure 6.7 Aerial photo of surface plume 34 minutes after disposal of dredged material at the site on March 20 2010 (photo: Terry Healy).

6.3 SURVEY 4 ECHOSOUNDER IMAGERY

Echosounder imagery displayed aboard the main survey vessels on April 25 2010 (Survey 4) was recorded using a tripod mounted hand-held video recording device. The monitor displaying the soundings did not include a time stamp so periodically during the image capture, a wrist watch was held in front of the camera to record the ongoing time. After that, actual time was correlated to the running clock of the video footage.

As previously mentioned, the ADCP system described in Report 3, was unable to capture water column soundings when the descending sediment was extremely dense. This only occurred in the first minutes after release while the main component descended to the seafloor. ADCP transects recorded in these moments often displayed gaps in backscatter data which were assumed to be areas of very dense material. Figure 6.8 shows a plot of ADCP Transect 1 recorded within minutes after release of dredged material on April 25 2010 where this loss of data is evident.

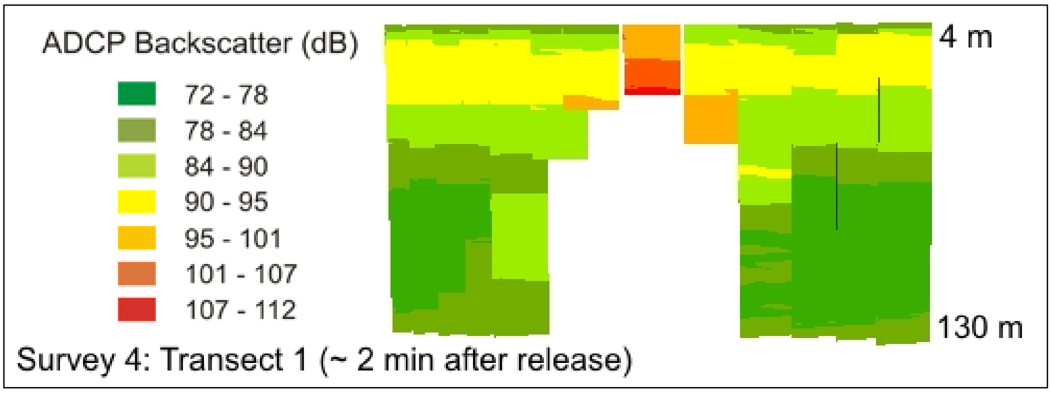


Figure 6.8 ADCP backscatter cross-section of transect 1 of Survey 4 recorded approximately 2 min after release of dredged material at the centre of the disposal site (white area in the middle of the transect indicates loss of data).

Figure 6.9 shows freeze-frame images from the echosounder monitor footage recorded during Survey 4. The images span from 1 - 28 minutes after disposal. The echosounder image captured 1 min after disposal corresponds in time to ADCP transect 1 (Figure 6.8). Although the resolution of the ADCP backscatter data plot is significantly coarser, the shape of the area of lost data, somewhat like an upside-down wine glass, is very similar to that captured by the echosounder (Figure 6.9). By the time the ADCP transect was recorded, the density of material in the “stem” of the glass had decreased sufficiently to be registered by the ADCP system. Backscatter in that area was recorded at the maximum end of the range (107-112 dB). At the “bowl” of the glass, where there was a loss of data in the ADCP record, a very deep red colour was displayed in the respective echosounder image (Figure 6.9). The deep red colour similarly corresponded to the maximum end of the recordable range for the vessel sounder. It is therefore a reasonable assumption that density of material in the white area of the ADCP transect was too high to be registered by the system.

The remaining echosounder imagery, show detailed evolution of the descending material and the resultant plume. After 28 minutes, the majority of the material had either settled or dispersed so that only a small portion of the water column showed concentrations slightly above background levels.

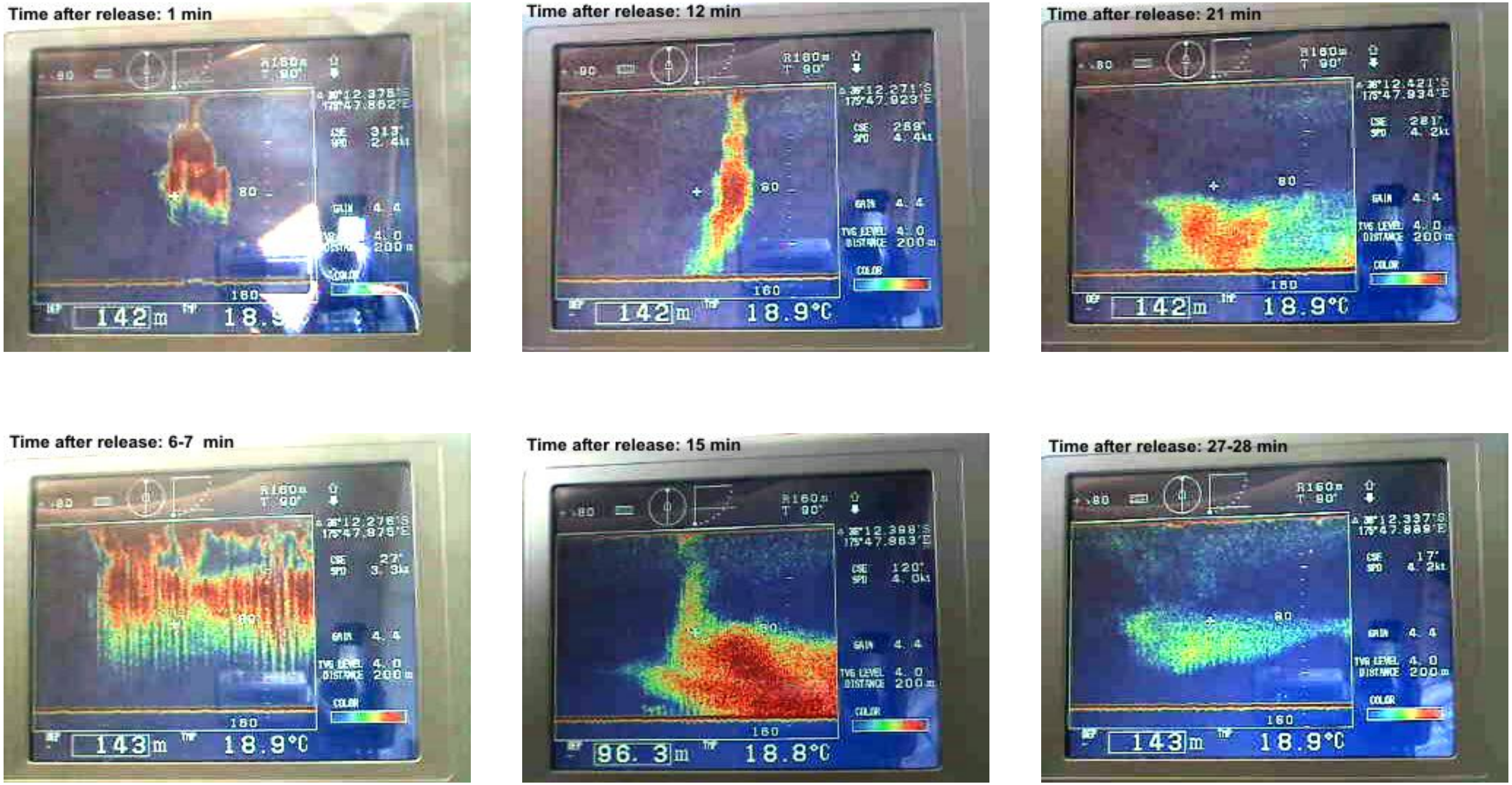


Figure 6.9 Freeze frame images of video footage recorded of the echosounder monitor aboard the main survey vessel during Survey 4 on April 25 2010

6.4 POST-DISPOSAL SEAFLOOR VIDEO

On July 26 2010, underwater video was recorded and several locations across the disposal site as well as at three control sites. The purpose of this survey was to determine if (i) the dredged material disposed there in March and April 2010 could be identified and (ii) if so, at what distances from the release location was it identifiable.

The underwater recording device, borrowed from Leigh Marine Lab, University of Auckland, was designed to record footage from approximately half a metre off the seafloor via a 4-legged frame (Figure 6.10). Though the frame was designed to be stationary once put down on the seafloor, it was possible to pan the camera from approximately 0° to 90° vertically, and approximately 360° horizontally via a cable connected to an on deck control system (Figure 6.10b&c). Lighting could also be controlled via a dimmer housed in the same control box.

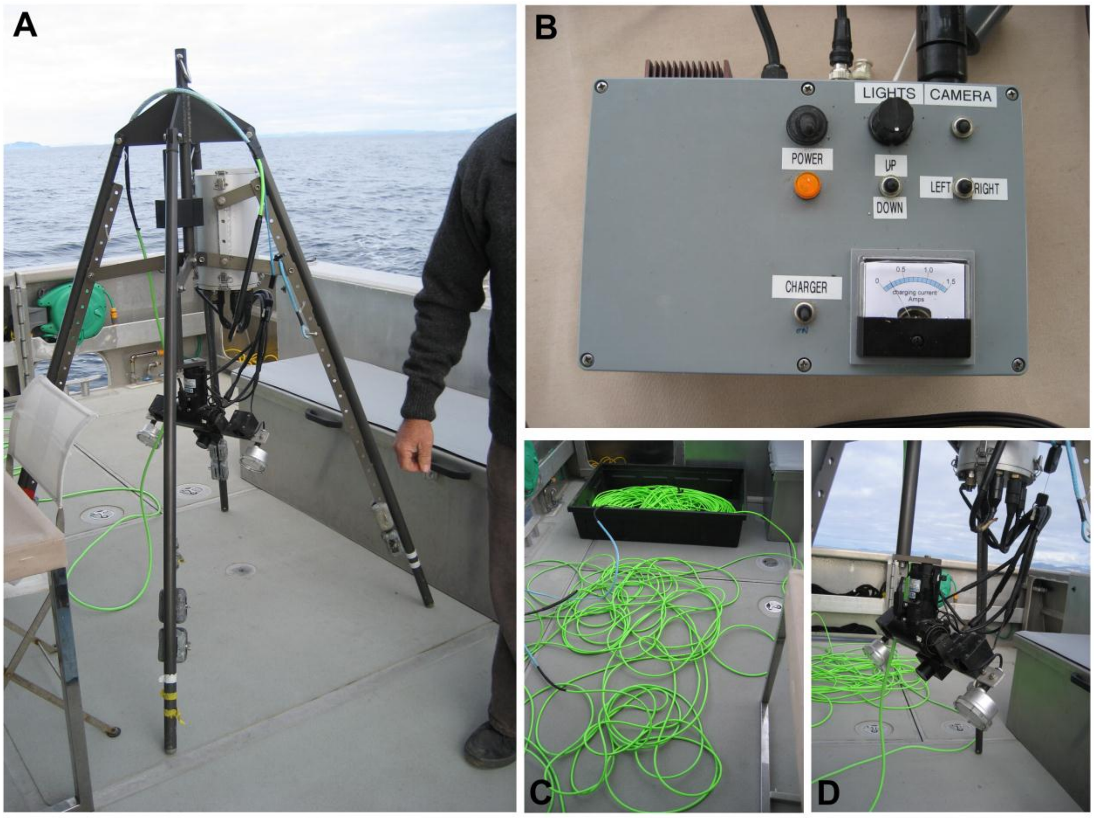


Figure 6.10 A) frame-mounted underwater video recording system used to film the seafloor at the disposal site following disposal of approximately 4800 m^3 of dredged material in March and April 2010, B) onboard control system for panning and lighting, C) cable for controlling camera and real-time viewing, and D) close-up of camera flanked by lighting units.

Footage was recorded at 9 sites within the disposal site boundary and at 3 control sites approximately 5 km to the east of the site and within the Territorial Seas (Figure 6.11). At each site, after the device made contact with the seafloor, the camera was panned up and to the left at the maximum angle and footage was then recorded systematically from left to right and right to left at progressively smaller vertical angles until the camera reached the minimum vertical angle. Lighting was adjusted accordingly throughout recording to maximise visibility. Each site was filmed for approximately 3-5 minutes.

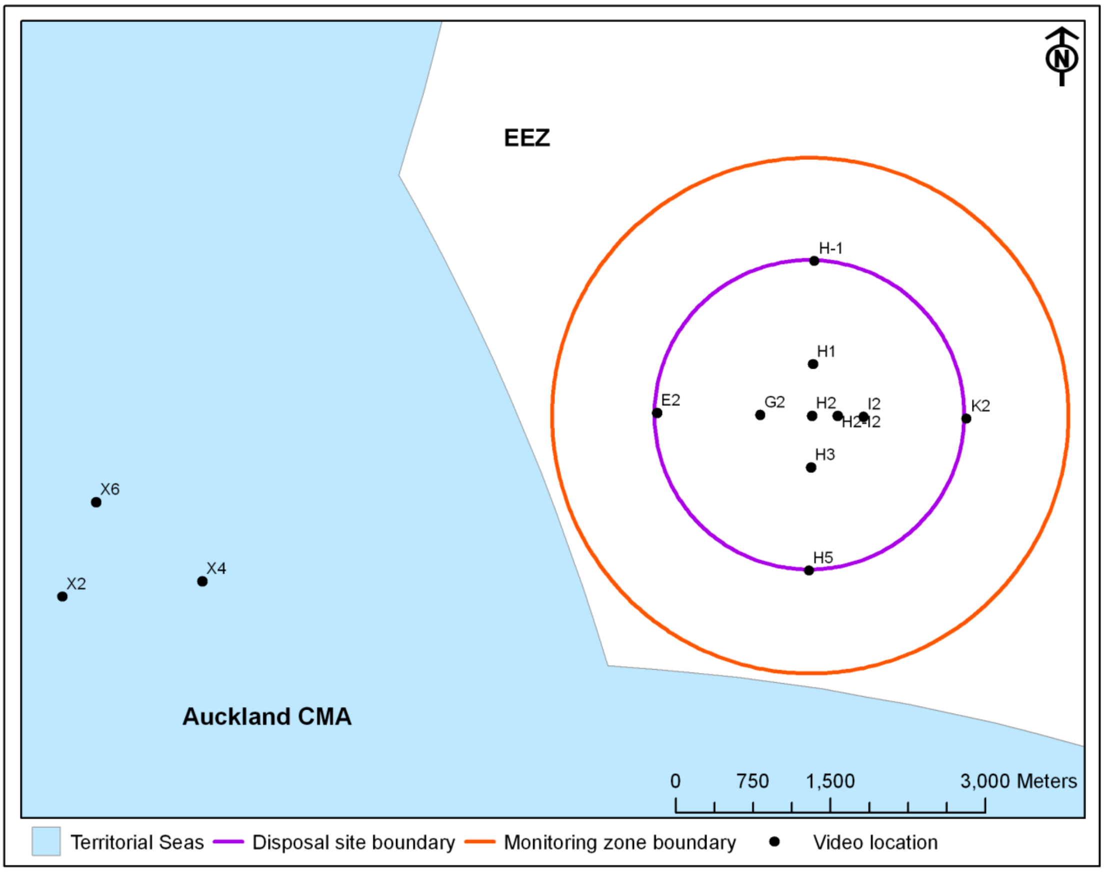


Figure 6.11 Map location of the proposed disposal site, monitoring zone, Territorial Sea/EEZ boundary, and locations where underwater video was recorded after disposal of approximately 4800 m^3 of dredged material.

Representative freeze-frame snapshots of each site are shown in Figures 6.12-6.14. If possible, one freeze-frame snap shot representing the majority of the seafloor features recorded at each site was chosen. However, at sites where the presence of dredged material was quite obvious, several snap-shots were chosen. In general, the best indicator of the presence of dredged material was seafloor relief (small bottom topographic features better visualised by shadows) which was best observed when the camera was positioned at greater vertical angles. When the camera was directed toward 0° (straight down) the seafloor relief appeared flat due to the absence of shadow. Accordingly, all snapshots chosen are from when the camera was positioned at large vertical angles.

Table 6.1 summarises the seafloor relief descriptions of each site and includes comments on the presence of dredged material. It should be noted that descriptions and interpretations gleaned from video clip observations are somewhat objective and also depend of the quality of the clip. The following is the set of descriptive terms and their intended meanings included in the Table 6.1:

Scarred- markings along the seafloor giving the impression of a “micro relief”; most likely scarring is the result of biological activity (e.g. worm burrows, trails, etc) and therefore it can be presumed that the sediment in that area has not be recently disturbed by forces such as currents or deposition of fresh sediment.

Smooth surface- generally, the opposite of scarred; very little in the way of scarring suggesting that the sediment had been recently deposited or eroded by currents; sometimes used in conjunction with *blanketed* which refers to the assumption that fine sediment from a disposal plume may have settled uniformly over the area after release of dredged material (though it should be noted that a smooth surface might also be expected if in fact there was very little biological activity).

Blocks-dense clumps varying in size that look like rocks but are the colour of the surrounding sediment; it is presumed that these features constitute the "main component" (described in Report 3) of the dredged material which descended very rapidly after release and deposited not far from the release location; the dredging method used (backhoe) tends to retain a larger proportion of the *in situ* structure of the dredged material compared to other methods, so it is reasonable that blocks would be present.

Hummocks- refers to small isolated mounded features with a smooth surface which could potentially have been formed from blanketing by entrained fine sediment over medium to large sized blocks of dredged material which would cause the block to appear more like a smooth mound rather than a distinct exposed block.

Lumps- similar to hummocks but smaller; bumps in the seafloor with a smooth surface; possibly small blocks of dredged material later blanketed by settling fines.

Table 6. Summary of observations on seafloor relief made from video footage recorded after disposal of approximately 4800 m^3 of dredged material

Site	Seafloor relief description	Presence of disposed material
E2	Uniformly scarred, burrows, depressions	Not likely
G2	Smooth surface, hummocks	Probably; medium sized blocks blanketed by fine material
H-1	Smooth surface, a few small lumps, some scarring/worm burrows	Possibly; small sized blocks blanketed by fine material
H1	Smooth surface, some scarring/worm burrows	Possibly; surface looks somewhat blanketed, but also with scarring
H2	Many exposed blocks; smooth in between blocks	Most likely, large and small blocks of material interspersed with smooth blanketed or eroded areas
H2/I2	Smooth surface, hummocky, lumpy	Most likely, medium and small sized blocks blanketed by fine material

H3	Smooth surface, a few small lumps, some scarring/worm burrows	Possibly; surface looks somewhat blanketed, but also with scarring
H5	Uniformly scarred, burrows, depressions	Not likely
I2	Smooth surface, some scarring/worm burrows, depressions	Possibly; surface looks somewhat blanketed, but also with scarring
K2	Uniformly scarred, burrows, depressions	Not likely
X2	Uniformly scarred, depressions, worm burrows	Not likely
X4	Uniformly scarred, depressions, worm burrows	Not likely
X6	Uniformly scarred, depressions, worm burrows	Not likely

At the centre of the site (Site H2), where the dredged material was released, many blocks of dense material were observed (Figure 6.12 & 6.13). Typically, the blocks appeared exposed with no build-up of sediment around or covering them. However, the substrate in between blocks appeared smooth with very little scarring. This pattern seems consistent with typical disposal mechanics where the densest material (the blocks least disturbed in the dredging process) would descend rapidly to the seafloor and deposit very near to the release location. The turbulent jet of material (with the blocks mostly at the leading edge), would impact the seafloor with enough energy to erode the soft native materials leading to mixing with entrained disposed material. The entrained material may settle rapidly, but depending on particle size, would likely be dispersed radially outward from the point of impact and settle some distance away. The erosive conditions at the point of impact would therefore likely leave behind the dense blocks of material and in absence of blocks, patches of smooth sediment that have been wiped clean of trademark biological scarring that builds up over time. Initially, the blocks would have appeared darker than the surrounding sediment and in fact the darker colour of the dredged material was observed in cores retrieved very soon after disposal at Site H2 (see Report 1). However, after several months, oxidation would have changed the colour of the dredged material to one very similar to that of the native sediments, so it is not surprising that colour variations were not observed in the video clips.

With the exception of one site, all other sites with evidence of dredged material or evidence of processes involved in disposal mechanics are within 500 m of the disposal release location. However, large exposed blocks of dense material were only identified at Site H2 indicating that the majority of the deposited material was confined to the vicinity of the point of impact. At Sites H1, G2, I2, H2/I2, H3 as well as at Site H-1 varying degrees of smooth versus scarred substrate were observed. As mentioned above, smooth substrate may be an indication of either erosion from the turbidity current, but more likely at distances away from the point of impact, a smooth substrate could be the result of blanketing by entrained fines dispersed away from the point of impact. Also somewhat common at these sites, were the appearance of hummocks and lumps, topographic features that protrude from the seafloor but in general had smooth surfaces indicative of recent deposition. While it is possible that these features were just a part of the native substrate and then blanketed after deposition of dispersed fines, another explanation is that some of the dense blocks of material may have rolled along the seafloor with the turbidity current and deposited further away from the point of impact. This seems particularly feasible at Site H2/I2 which is only 250 m from the release location (Site H2) especially considering the natural degree of error in "hitting the mark" during disposal operations. Indeed, cores retrieved from Site H2/I2 immediately following disposal operations did contain black dredged material, albeit smaller quantities that those retrieved from Site H2 (see Report 1). It should be mentioned that the degree of certainty about the presence of dredged material in the form of blocks or just settled fines at Sites H1, G2, I2, H2/I2, H3 and H-1 is much lower due to the lack of obvious blocks such as those observed at Site H2.

The smooth substrate noted at Site H-1 may be explained by the large patch of dense material identified to the north of the centre of the site seen in the MBES backscatter map (see Report 2). In Report 3, it was suggested that the patch could be correlated to the load disposed on April 10 2010, which was surveyed at 720 m^3 (the largest of the 9 loads disposed). The energy of the turbidity current would be expected to increase proportionally with the size of load disposed resulting in an increased distance over which entrained material could settle. That combined with a point of impact 250 m north of H2, it is not unreasonable to conclude that settled fines resulting in a smooth appearance of the substrate might be observed at Site H-1 especially considering that the drift current was directed toward the north on that day (see Report 3). However, during the plume monitoring survey undertaken on April 10, dispersed material was not detected by the ADCP in significant concentrations further than 600 m north of Site H2 after 1 hour, so any fines settling beyond that distance would most likely be inconsequential. Furthermore, it is possible that the smooth appearance of the substrate at Site H-1 was merely a coincidence and was not the result of the settling of fines following disposal of dredged material.

The remaining sites, K2, H5, E2, and the control sites X2, X4, and X6 showed the tell-tale scarring most likely to be predominantly the result of biological activity. However, a general unevenness would be expected to develop over time through a combination of biological activity and common geomechanical processes such as consolidation, patchy scouring, and 'mini' slope failures (e.g. mounds built up through biological activity can fail just like any slope steeper than its stable angle). As such, disposed dredged material is not readily identifiable at Sites K2, H5, and E2. Control Sites X2, X4, and X6 are examples of pristine conditions and appear similar in the amount of scarring and unevenness observed at K2, H5, and E2.

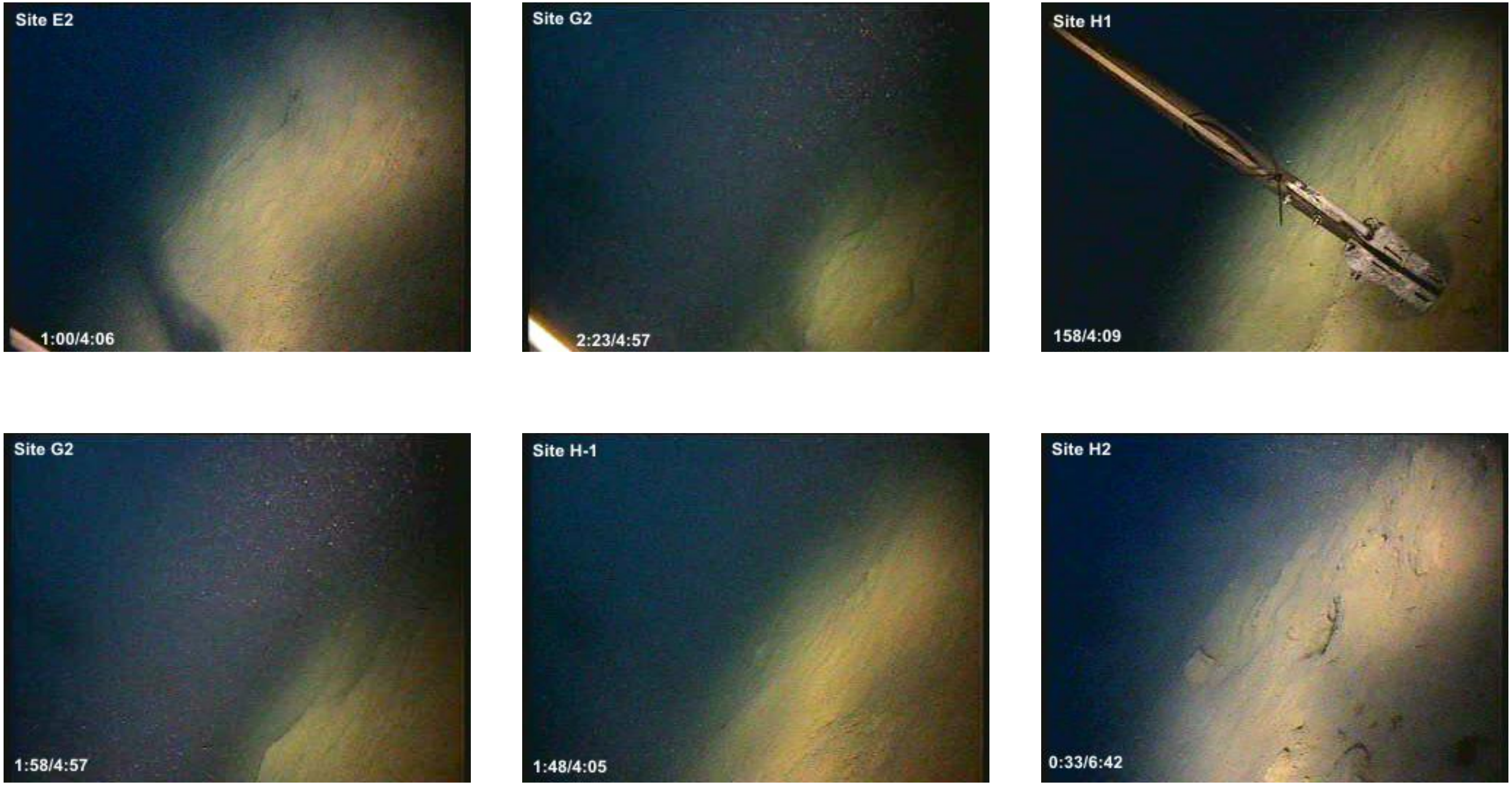


Figure 6.12 Freeze frame images of underwater video footage captured on July 26 2010 at sites: E2, G2, H-1, H1, and H2 following disposal operations.

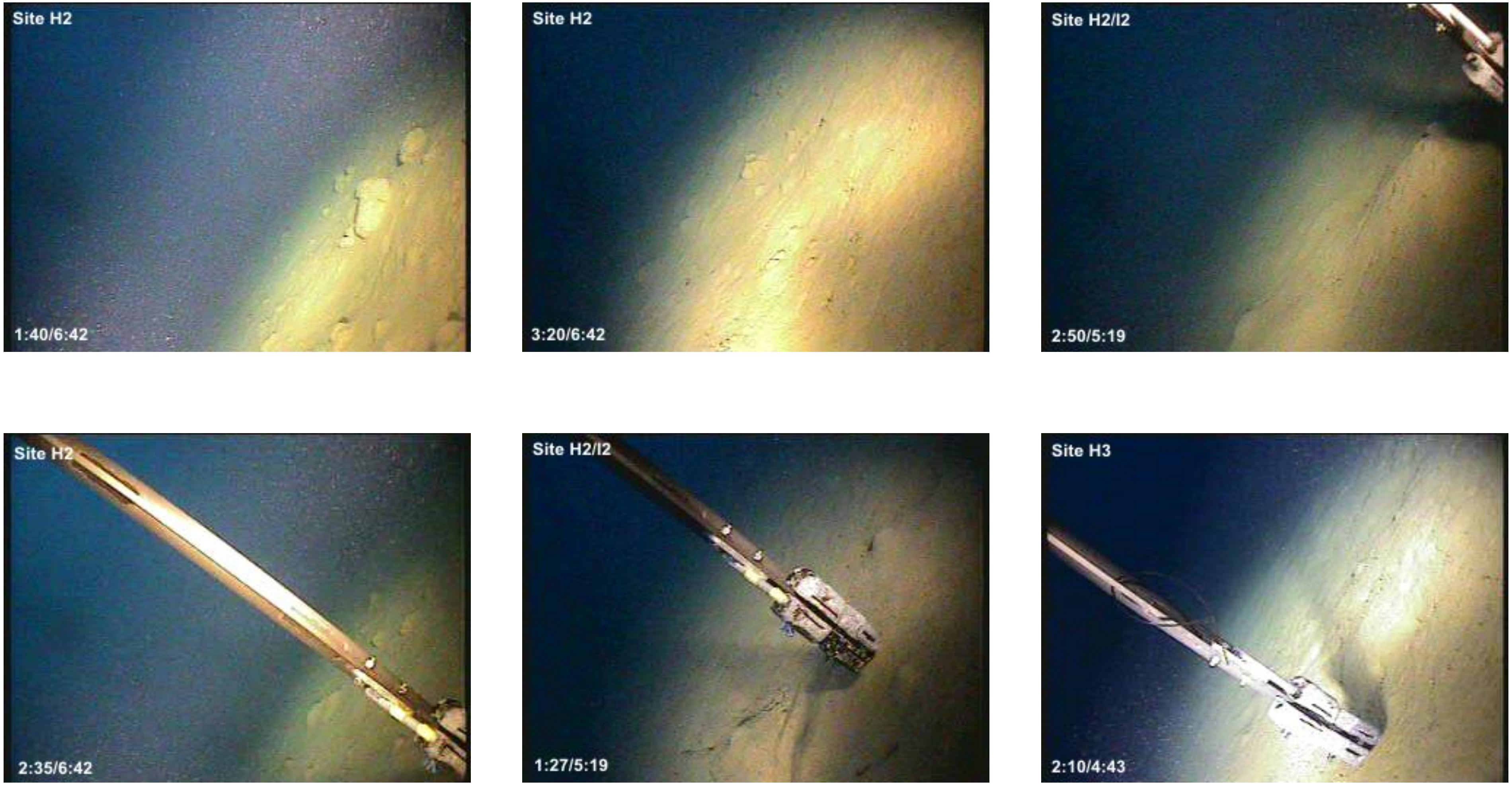


Figure 6.13 Freeze frame images of underwater video footage captured on July 26 2010 at sites: H2, H2/I2, and H3 following disposal operations.

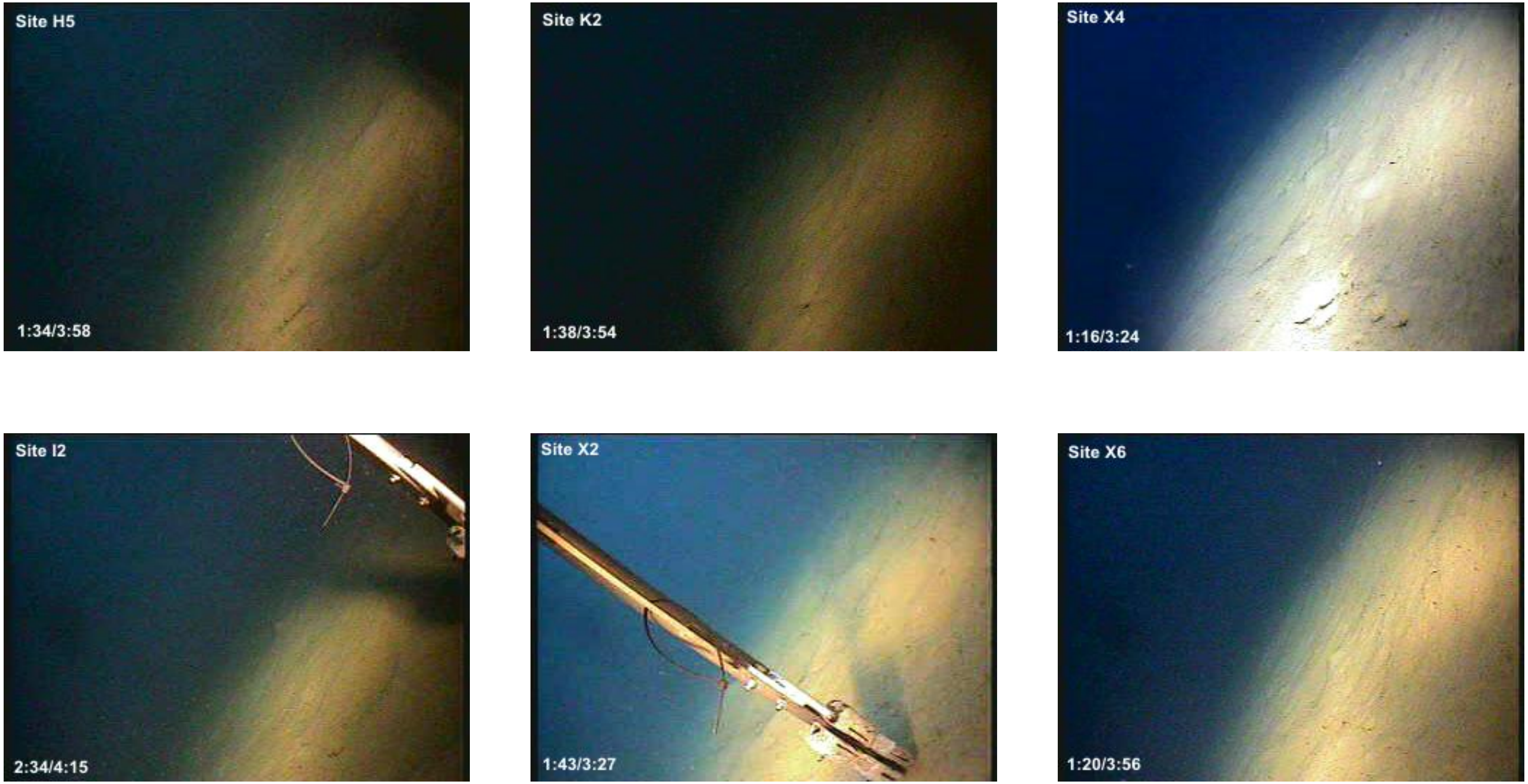


Figure 6.14 Freeze frame images of underwater video footage captured on July 26 2010 at sites: H5, I2, K2, and control sites X2, X4, and X6 following disposal operations.

6.5 CONCLUSIONS

6.5.1 Surface plume: aerial observations

On the day that aerial photographs were taken, the surface plume resulting from disposal of dredged material at the centre of the site was approximately 150 m in length and 20 m in width. Initially, the plume showed up as a distinct elongated turbid cloud, but after about 30 min, it appeared substantially diluted and somewhat more dispersed. The spatial extent of the surface plume was greatly influenced by the method by which the material was disposed. Material was released from a moving towed hopper therefore material entered the water over the distance that the hopper had moved during that time. So, it can be expected that the faster the hopper is towed, the larger the spatial extent of the plume and vice versa.

6.5.2 Plume monitoring: echosounder observations

In general, echosounder images displayed by the system installed on the main survey vessel corroborated backscatter data that was recorded by the ADCP system during the fourth plume monitoring survey on April 25 2010. Disposed material appeared very dense and confined as it descended to the seafloor in the first several minutes after it was released. After approximately 20 min, the entrained material had mainly settled out of the surface waters and appeared closer to the seabed. Thirty minutes after release, elevated turbidity was still apparent, but much less so than in the first minutes after release.

From the plume monitoring surveys described in Report 3, one unanswered question was on the validity of the assumption that the data gaps usually seen in the first couple transects recorded by the ADCP were due to very dense material in the water column that exceeded the recordable range of the system used. Images recorded from the vessel echosounder in the first couple minutes verified this assumption. Fortunately, the range of vessel sounder was higher than that of the ADCP system and did in fact show that where data was missing in the ADCP record, very dense material was present in the water column. However, as the vessel sounder does not produce quantitative data, it is better to use it as a complement to the ADCP system in monitoring plume conditions.

6.5.3 Dredged material fate: video observations

Video clips recorded at the seabed at several locations within the disposal site showed evidence of the presence of dredged material or evidence of possible disposal mechanics processes. At the centre of the site, the location for release of the 9 loads of material disposed over March and April 2010, a large number dense blocks of material resembling rocks, but with the colour of the surrounding sediments were observed on the surface of the seabed. It is reasonable to assume that these objects constituted the main component of the disposed material, that which descended rapidly and deposited very close to the release location, because they did not appear so conspicuously at any of the other locations filmed. In the areas between the blocks, at the centre of the site, the seafloor was smooth suggesting erosion by turbidity currents which would have entrained the soft native sediments in the vicinity of the point of impact during the disposals.

At sites filmed 250 m and 500 m from the centre, the presence of dredged material was not quite as obvious as that observed at the centre of the site. Based on well-established disposal mechanics processes it is reasonable to assume that the smoothness of the seabed surface may be the result of the settling of fine sediments dispersed from the point of impact near the centre of the site. The fine sediments might have deposited as a blanket over the surface filling in the natural micro-relief of the seabed that develops over time through biological activity and geomechanical processes especially in areas where oceanic currents are very slow. However, because the layer of settled fines would not be expected to be very thick, it was difficult to verify that the video clips did in fact show a smooth surface versus a scarred surface (indicating no recent deposition) not to mention whether or not the smooth surface was in fact a result of settled fines. For that reason, it cannot be concluded with absolute certainty that dredged material was observed at sites 250 m and 500 m from the centre, but at the site 250 m from the centre, the likelihood is appreciably greater.

Video clips recorded at the four sites 1500 m from the centre, showed very little in the way of evidence of dredged material. It is not likely that the material dispersed to this distance, with the exception of the site 1500 m to the north of centre where some surficial smoothness of the seabed was observed. However, the interpretation that it may be the result of settled fines from the disposal on April 10 2010 is somewhat dubious and cannot be considered evidence of dredged material with absolute confidence.

The following summarises the main conclusions drawn from the underwater video clips recorded on July 26 2010 following disposal of 9 loads of dredged material (totalling ~4800 m^3) throughout March and April 2010:

i. At the centre of the disposal site it is very likely that dredged material was present;

ii. At sites 250 m and 500 m away from the centre, there is some evidence of the presence dredged material, but it cannot be concluded with absolute certainty;

iii. At the sites 1500 m from the centre, it is very unlikely that dredged material was present.

To increase the certainty of observations, video clips should be recorded within days after disposal of dredged material especially as in this case where the material disposed had a distinctly different colour (black) due to anoxic conditions where it was dredged. However, considering the length of time that had passed between the disposals and the underwater video survey, it was very encouraging that material was quite obviously still present at the centre of the site, even if it had oxidised and changed to a colour similar to that of the native sediments. Furthermore, the fact that dredged material was not conspicuous at the other sites visited suggests that most of the material disposed deposited at the centre of the site and did not move during the 3 months prior to the video survey.

REFERENCES

ADM Elektronik (2003). BIO-FISH Towed-system (Serial number 8-102): User's manual. Analoge und digitale Meßsysteme (ADM) Elektronik, 77p.

ANZECC (2000). Australia and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1, The Guidelines (Chapters 1-7). The Australia and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ). Paper No. 4- Volume 1 (Chapters 1-7), October 2000.

APHA (1997). 2540 D Total Suspended Solids Dried at 103–105°C. Standard methods for the examination of water and wastewater 20th Edition, American Public Health Association (APHA), American Water Works Association, Water Environment Federation.

Aubeny, C.P. and Shi, H. (2006). Interpretation of Impact Penetration Measurements in Soft Clays. *Journal of Geotechnical and Geoenvironmental Engineering*, 132(6), 770-777.

Beyer, A., Chakraborty, B. and Schenke, H. 2007. Seafloor classification of the mound and channel provinces of the Porcupine Seabight: an application of the multibeam angular backscatter data. *International Journal of Earth Sciences* 96(1): 11-20.

Bioresearches (2009). Pine Harbour Marina Limited – Pre-dredging marina basin biological and sediment characteristics report, prepared by Bioresearches, Auckland New Zealand for Pine Harbour Marina Limited, 15p.

Campbell Scientific, Inc. (2008). OBS3+ Suspended solids and turbidity monitor: Operators Manual, 40p.

Davies-Colley, R.J. and Smith, D.G. (2001). Turbidity, suspended sediment and water clarity: a review. *Journal of the American Water Resources Association*, 37(5): 1085-1101.

Dayal, U., Allen, J.H., and Jones, J.M. (1975). Use of an Impact Penetrometer for the Evaluation of the In-Situ Strength of Marine Sediments. *Marine Georesources and Geotechnology*, 1(2), 73-89.

Flaim and Healy, 2008. Proposal for dredged sediment disposal on the continental shelf in the EEZ: Environmental Impact Assessment. Coastal Marine Group, University of Waikato, Hamilton, New Zealand. 88 pp.

Flaim, B.K., Stark, N., Moon, V., de Lange, W.P., Healy, T.R., and Kopf, A. (*in press*). Monitoring a dredged material disposal site on the continental shelf using the dynamic penetrometer *Nimrod*. *Proceedings of the Coastal Sediments '11*, Miami.

Gartner, J.W. and Cheng, R.T. (2001). The promises and pitfalls of estimating total suspended solids based on backscatter intensity from acoustic Doppler current profiler. *Proceedings of the Seventh Federal Interagency Sedimentation Conference*, March 25-29, 2001, Reno, Nevada.

Greenspan Technology. Turbidity Sensor TS100: User manual (Edition 3.0), 26p.

Greenspan Technology. Turbidity Sensor TS1200: User manual (Edition 1.2), 29p.

Hughes-Clarke, J., Mayer, L. and Wells, D. 1996. Shallow-water imaging multibeam sonars: a new tool for investigating seafloor processes in the coastal zone and on the continental shelf. *Marine Geophysical Researches* 18: 607-629.

Kongsberg, 2005. Product description EM3000 Multibeam echo sounder. Kongsberg Maritime, Horten, Norway. 36p.

Lurton, X. 2002. An introduction to underwater acoustics, principles and applications. Chichester, Praxis Publishing, Ltd.

Maritime New Zealand. 2009. Dumping permit application report - Coastal Resources Limited (Pine Harbour Marina): disposal of dredged spoil at new EEZ site east of Great Barrier Island. Permit no. 555. 12pp.

Maritime Safety Authority (1999). New Zealand Guidelines for the Sea Disposal of Waste. Advisory Circular Part 180: Dumping of Waste or Other Matter, Issue No. 180-1, 86p.

Preston, J., Parrott, D. and Collins, W. 2003. Sediment classification based on repetitive multibeam bathymetry surveys of an offshore disposal site. Paper presented at the Oceans, San Diego, CA. 69-75.

Sivaguru, K., and R. Grace. 2002. Habitat Species Diversity of Deep Reefs and Sediments at Great Barrier Island. Report for the Department of Conservation, Auckland Conservancy, 25p.

Stark , N. and Wever, T. (2008). Unravelling the subtle details of e*x*pendable *b*ottom *p*enetrometer (XBP) deceleration profiles. *Geo-Marine Letters*, 29(1), 39-45.

Stark, N., Hanff, H., and Kopf, A. (2009). Nimrod: a tool for rapid geotechnical characterization of surface sediments. *Sea Technology*, 50(4), 10-14.

Stark, N., Hanff, H., Stegmann, S., Wilkens, R., and Kopf, A. (2009). Geotechnical investigations of sandy seafloors using dynamic penetrometers. *Proceedings of the MTS/IEEE OCEANS'09*, Biloxi.

Stoll, R.D. and Akal, T. (1999). XBP-tool for rapid assessment of seabed properties. *Sea Technology*, 40(2), 47-51.

Stoll, R.D., Sun, Y., and Bitte, I. (2007). Seafloor properties from penetrometer tests. *IEEE Journal of Oceanic Engineering*, 32(1), 57-63.

Truitt, C. L. 1988. Dredged material behaviour during open-water disposal. *Journal of Coastal Research* 4(3): 489-497.

Turner Designs (2002). SCUFA Self-Contained Underwater Fluorescence Apparatus: User's Manual (2.1), 44p.

University of Colorado at Boulder. 2010. Interactive sea level wizard. *Sea level change*. Retrieved August 31, 2010, from http://sealevel.colorado.edu

USACE (1983). Engineering and design: dredging and dredged material disposal. Department of the U.S. Army Corps of Engineers (USACE), EM1110-2-5025.

ACKNOWLEDGEMENTS

During the extensive field campaigns the following people assisted in the field: Mike Roycroft, Gary Larsen, Ryan Larsen, Lyall Campbell, Dirk Immenga, Sean Kelley, Alex Schimel, Remy Zyngfogel, Andrew Wood, Simon Weppe, Sebastien Boulay and Denise Bruesewitz.

The Kongsberg EM3000 MBES was set-up on the MV Ten Sixty by Alexandre Schimel, Dr. Bradley Scarfe and Dirk Immenga with assistance from Colin Russel (Ocean Data Systems, Ltd.). MBES data was acquired with the assistance of Alexandre Schimel and Sebastien Boulay. MV Ten Sixty was operated by Mike Roycroft. MBES data was processed by Alexandre Schimel. Modelled tides were provided by MetOcean Solutions Ltd., New Plymouth, New Zealand.

Many people and organisations were involved in making the plume monitoring surveys possible. The BIOFISH system was provided by Dr. David Hamilton, Department of Biological Science, U. of Waikato and Chris McBride assisted in operation and data processing. Thank you to Nicole Hancock and Andrew Swales at NIWA Hamilton for providing instruction and facilities for sensor calibration. Thank you to Brett Grant at NIWA Wellington for assisting in obtaining and use of the GPS drifters. Colin Russel of Ocean Data Systems assisted in mobilisation of the RDI ADCP system as well as some data analysis

Nimrod surveys were funded in part by the German Research Association (via MARUM and GLOMAR, University of Bremen), and the German Academic Exchange Service (DAAD). *Nimrod* was made available by Professor Achim Kopf and the University of Bremen, Germany. Thank you also to Matthias Lange (MARUM), Christian Zoellner (MARUM), and Matthias Colsmann (AVISARO, Hannover). Nina Stark was instrumental in operation, processing and analysis of *Nimrod* data. Thank you to Dr. Vicki Moon for additional assistance with *Nimrod* data processing and analysis

Underwater video equipment was provided by Leigh Marine Lab of University of Auckland. Successful operation of the equipment was made possible with the assistance of Murray Birch. Aerial photos were provided by Prof. Terry Healy and Simon Male.

Mike Roycroft and Dirk Immenga were absolutely critical in not only field assistance, but also the enormous amount of organisation and mobilisation needed in order to make the surveys possible.

Many thanks to all the people that made this research possible.

APPENDIX I

Sediment Core Photos from Surveys:

September 2008

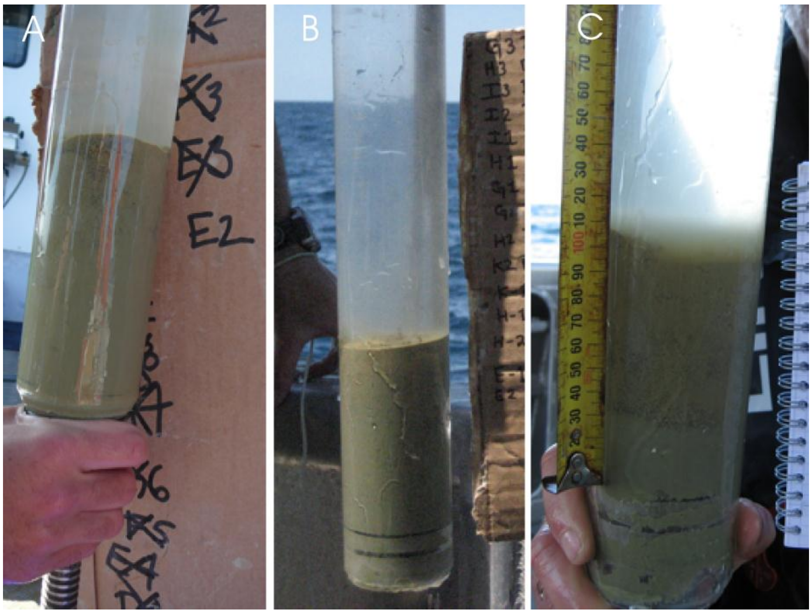
June 2009

January 2010

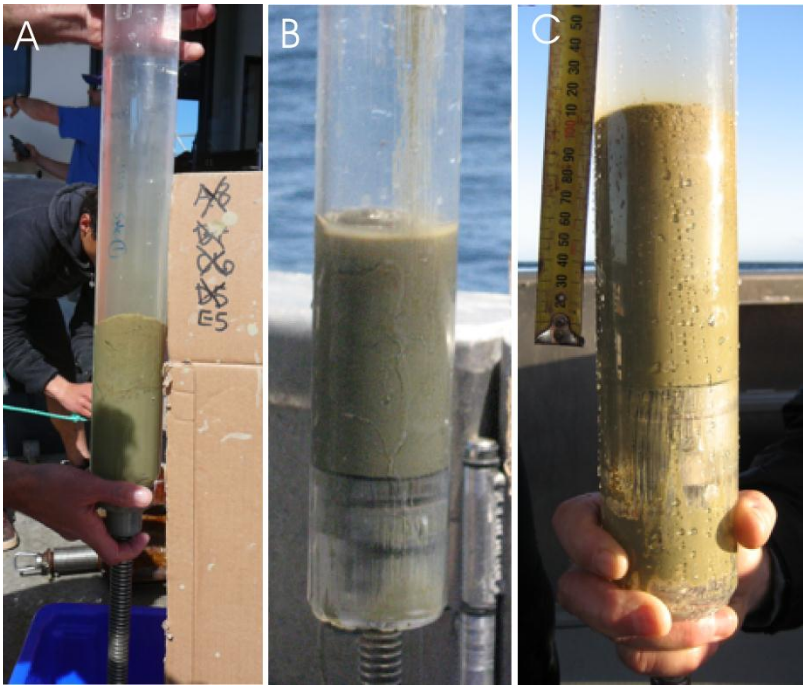
June 2010

Photos of a sediment core retrieved during each survey at each sample location are presented below (refer to Figure 1.2 for sample locations). For locations E2, E5, G2 and H1, photos A, B, and C are of cores retrieved during the September 2008, January 2010, and June 2010 surveys, respectively. For the remaining disposal site sample locations, photos A and B are of cores retrieved during the January 2010 and June 2010 surveys, respectively. For the control site locations (denoted by and 'X') photos A and B are of cores retrieved in June 2009 and January 2010, respectively.

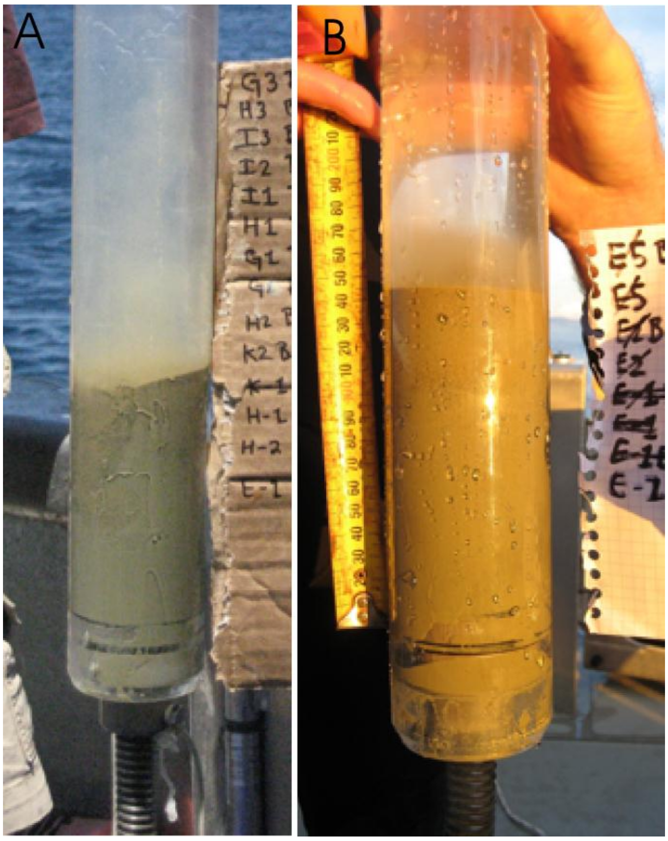
E2



E5

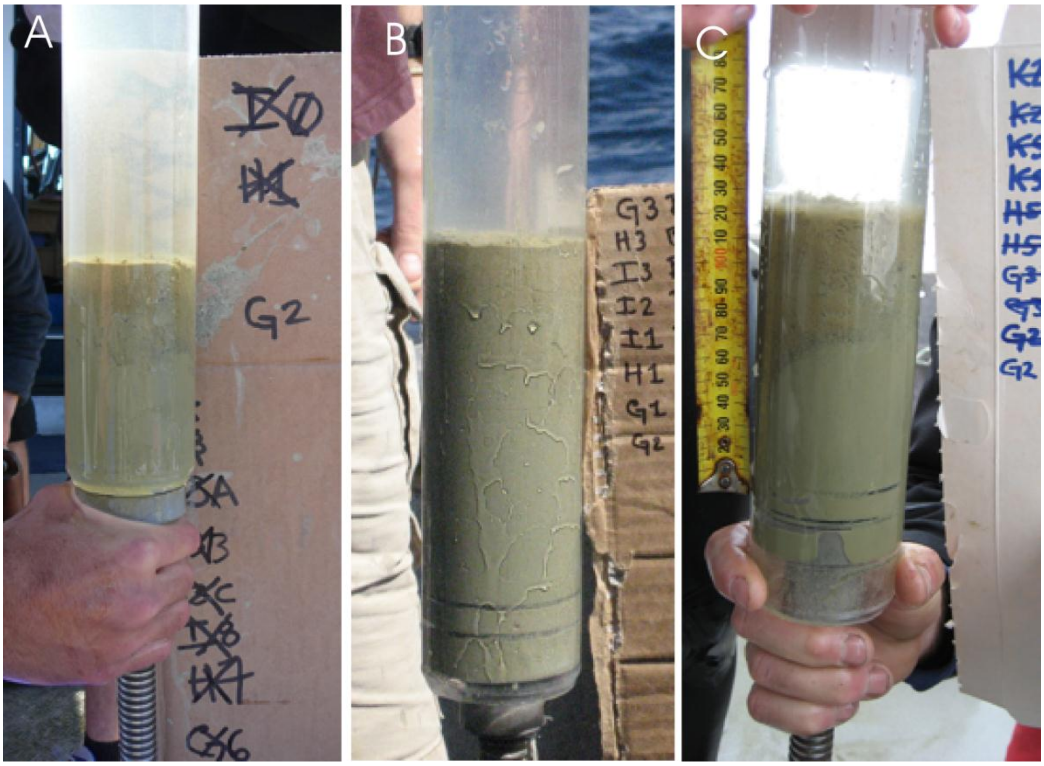


E-1

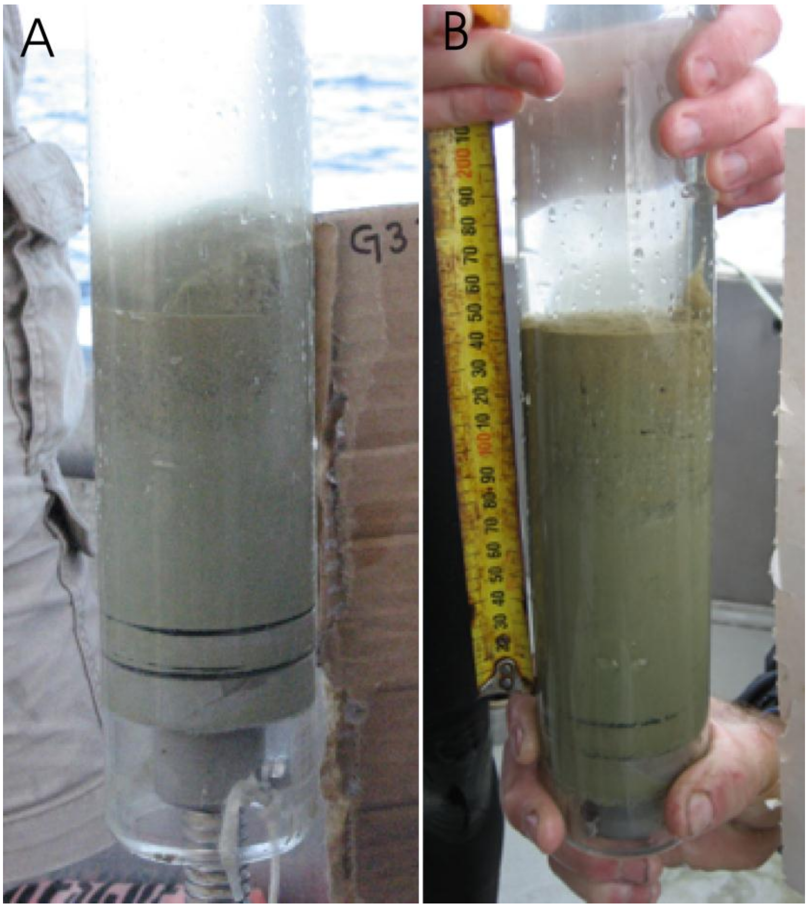


G1

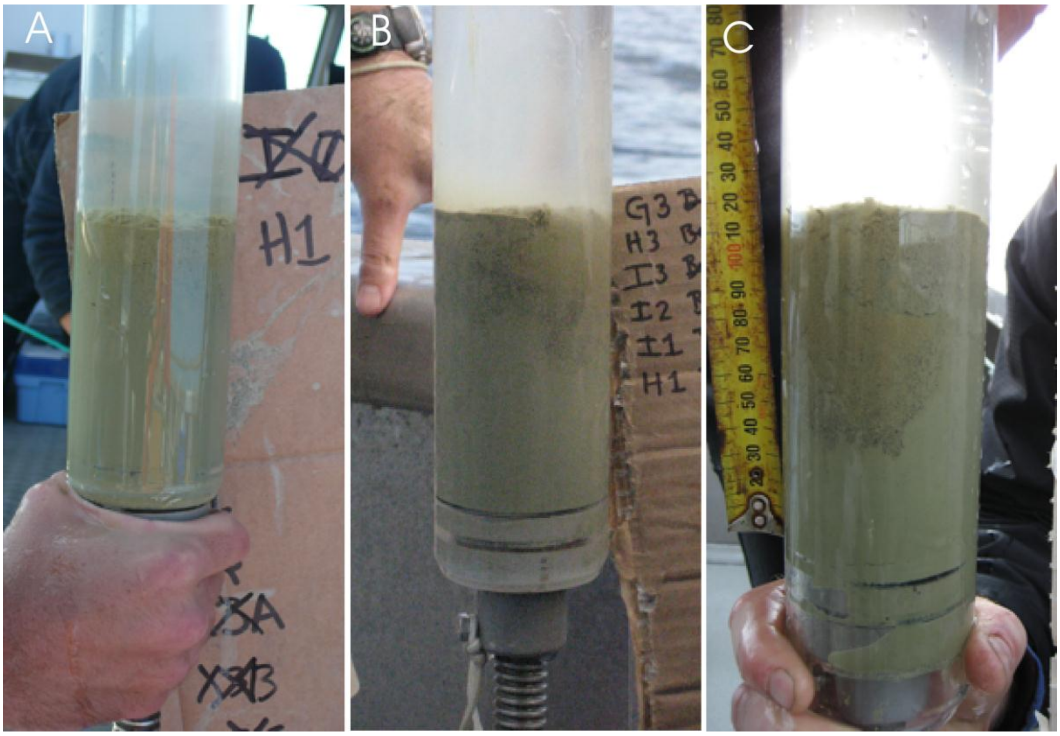
G2



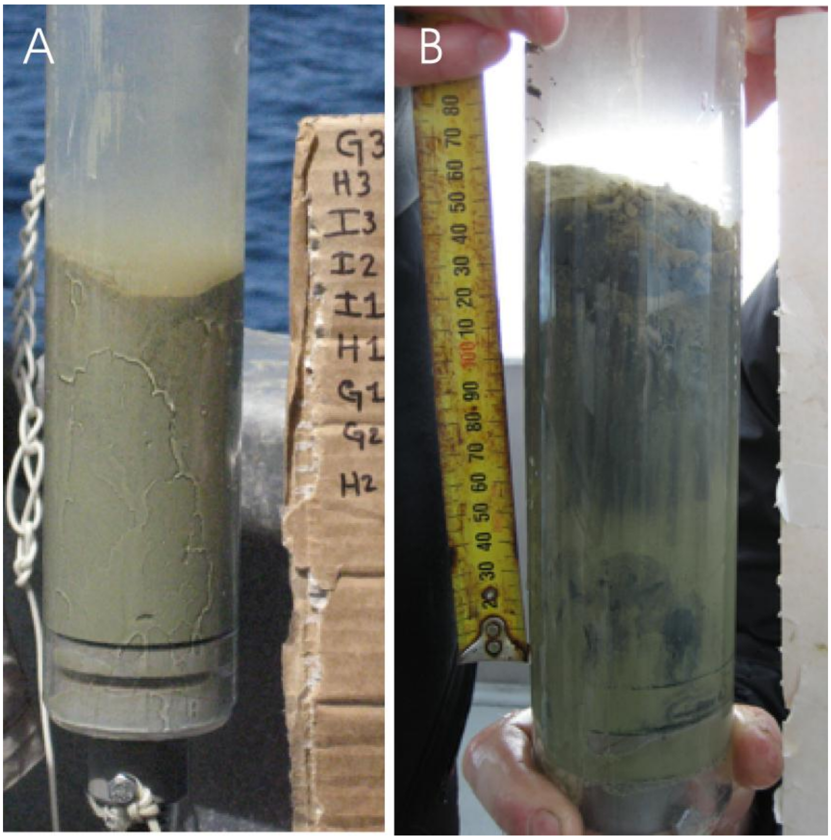
G3



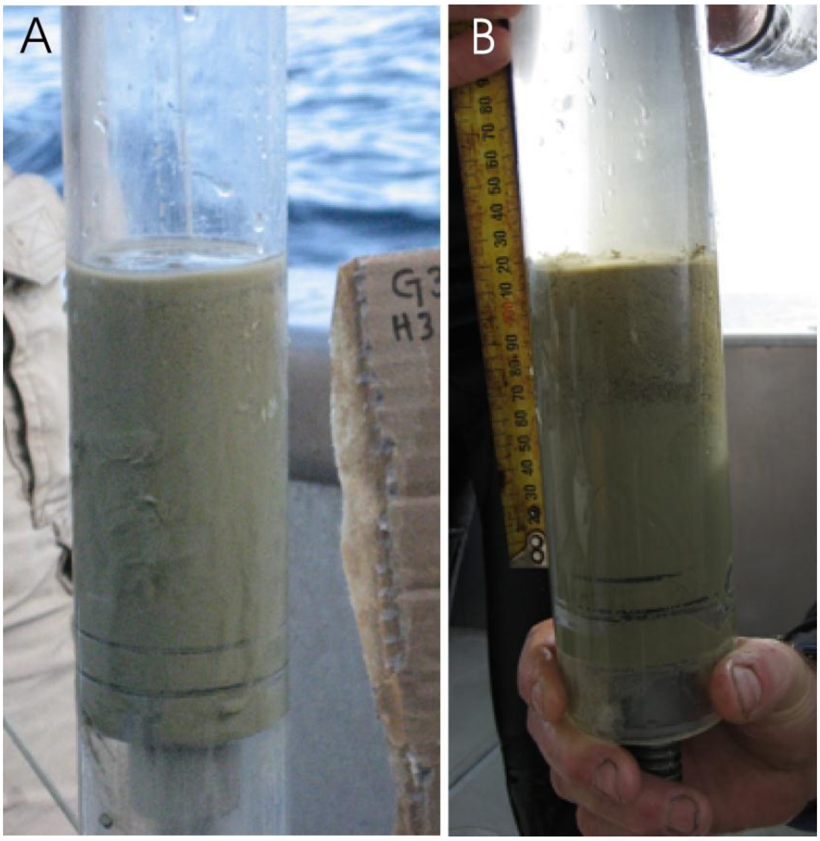
H1



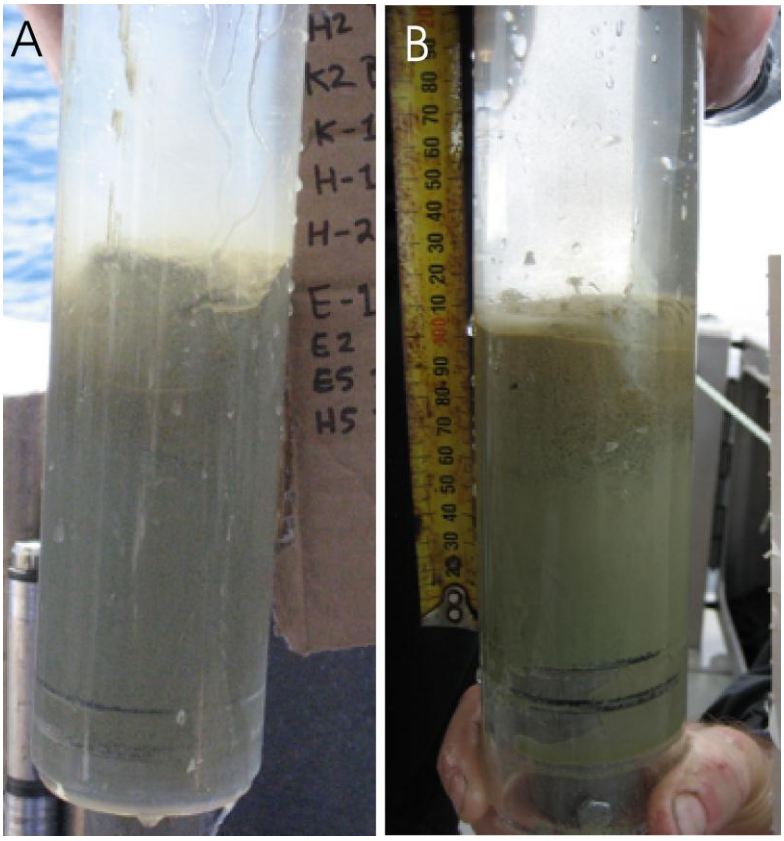
H2



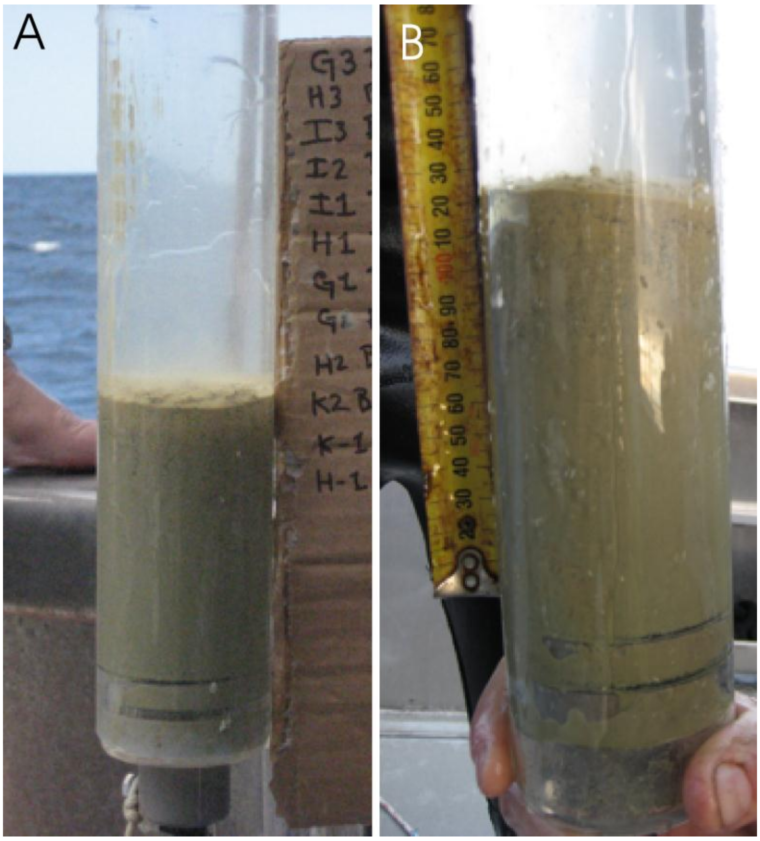
H3



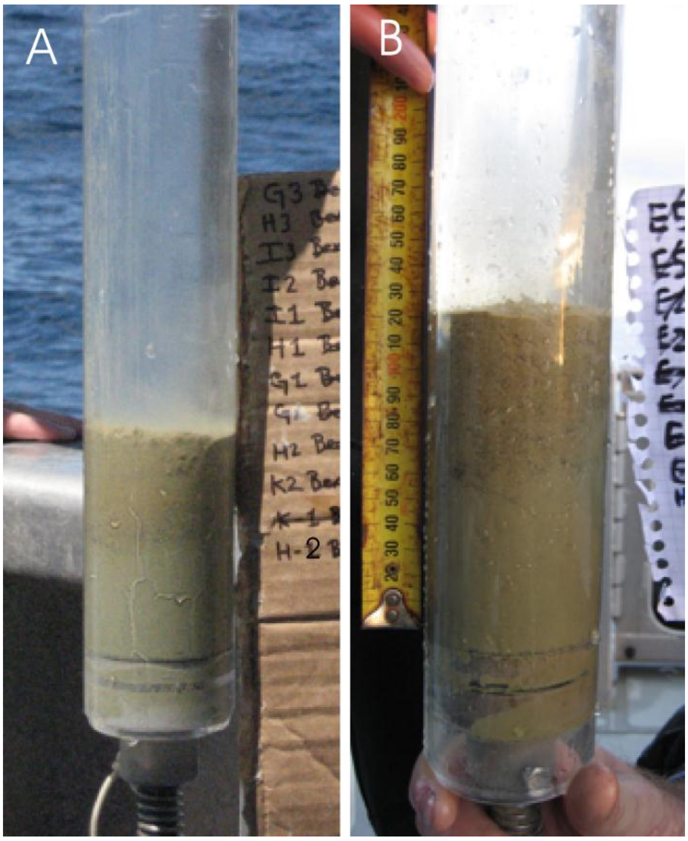
H5



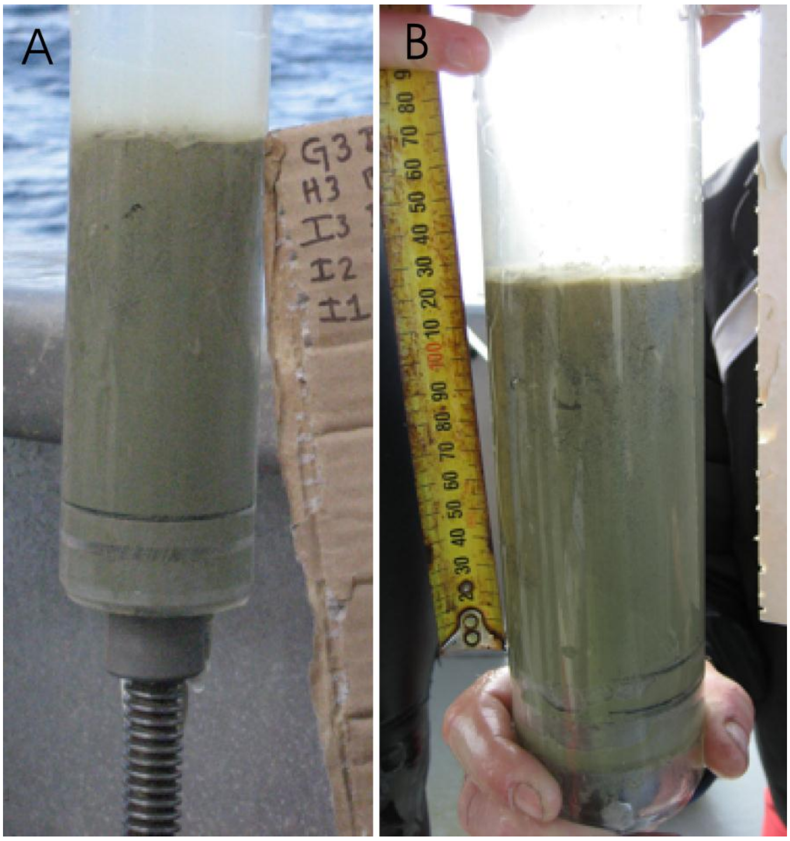
H-1



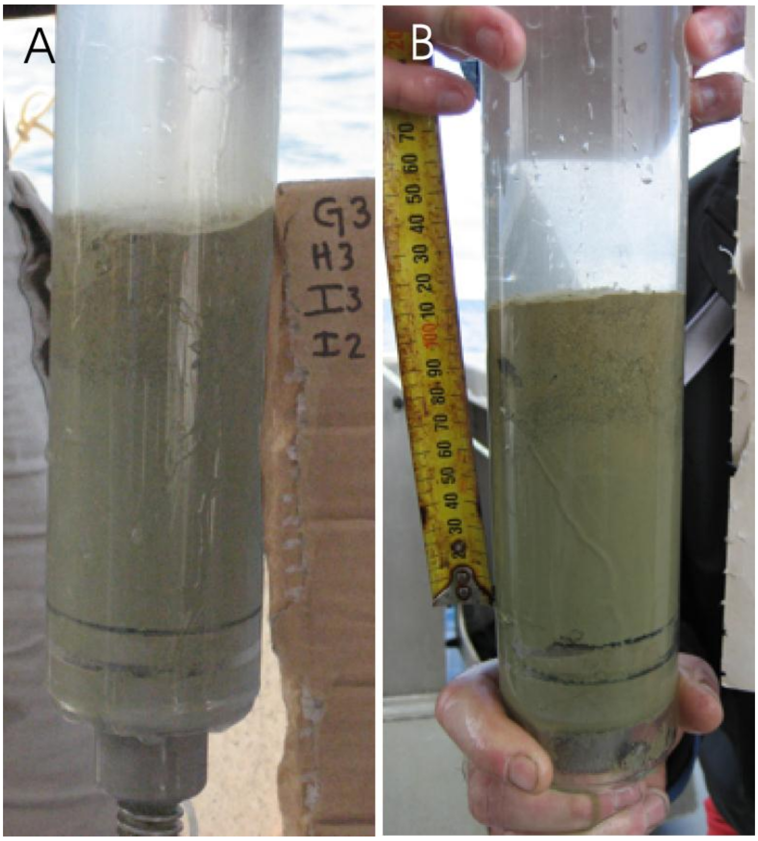
H-2



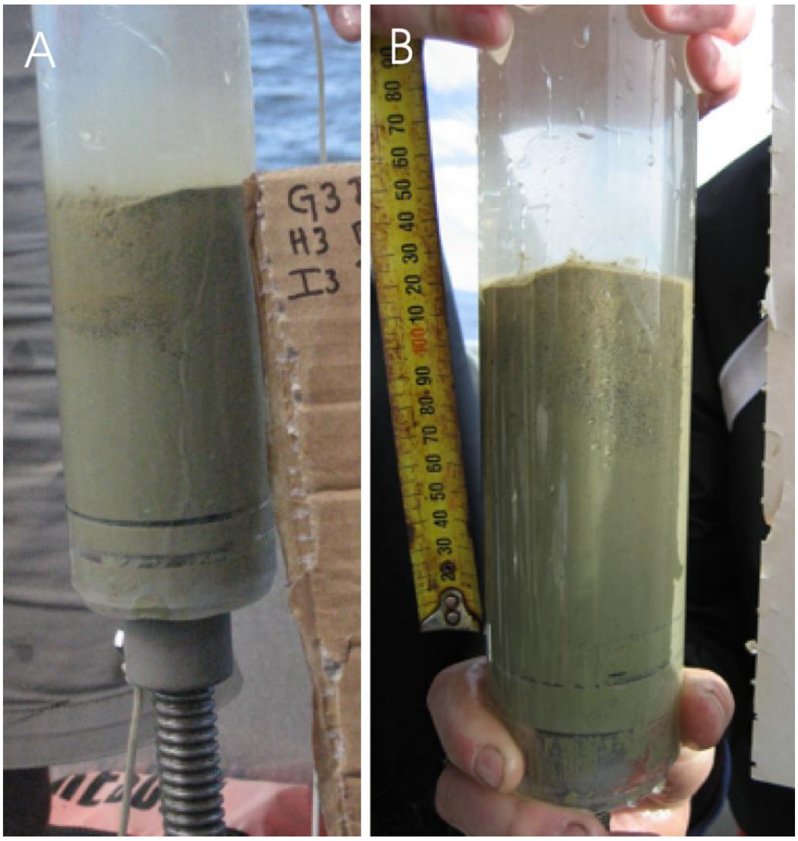
I1



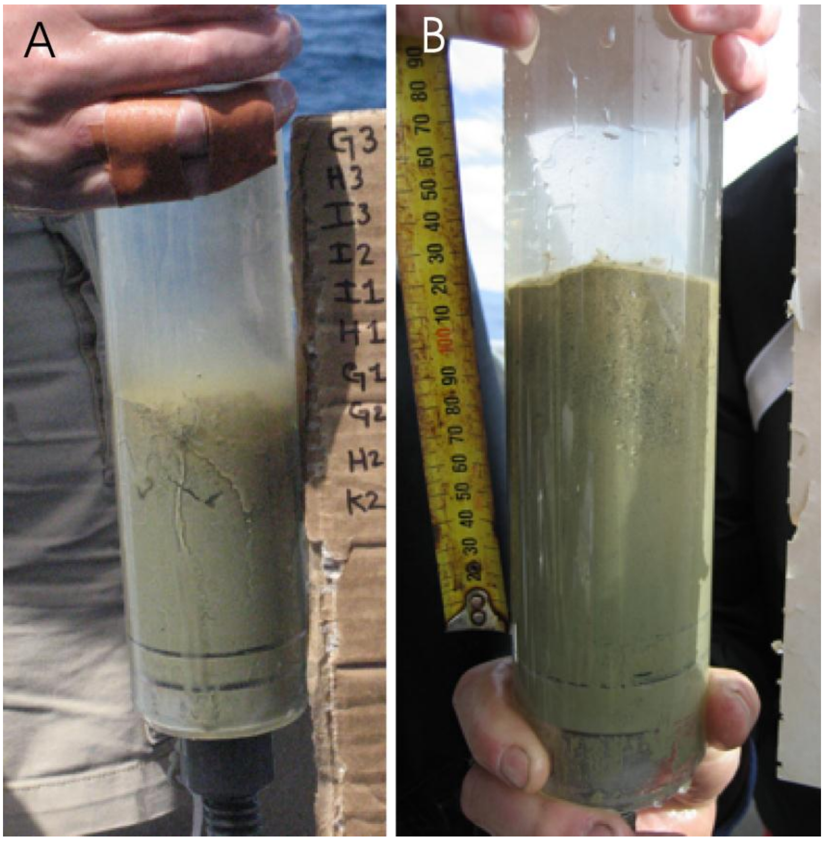
I2



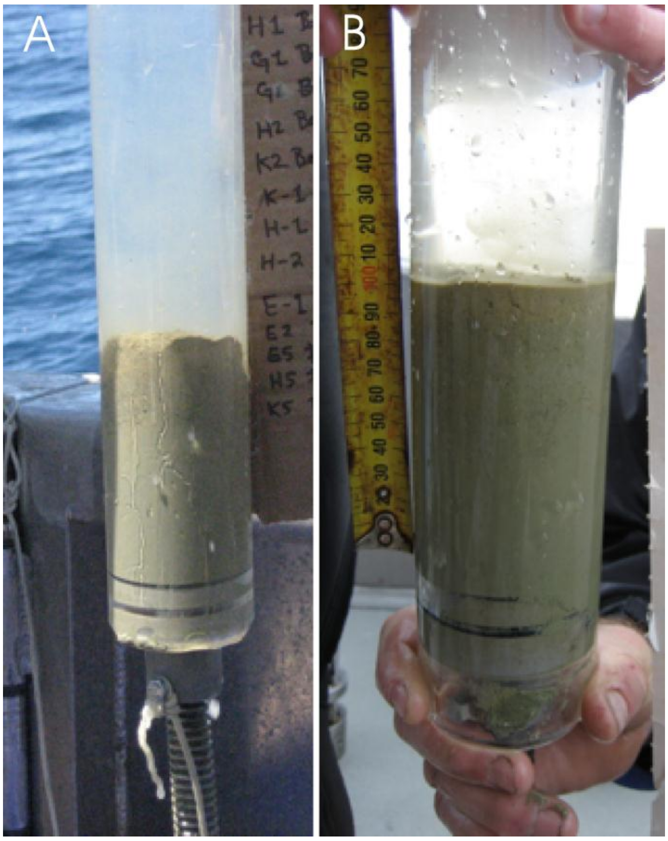
I3



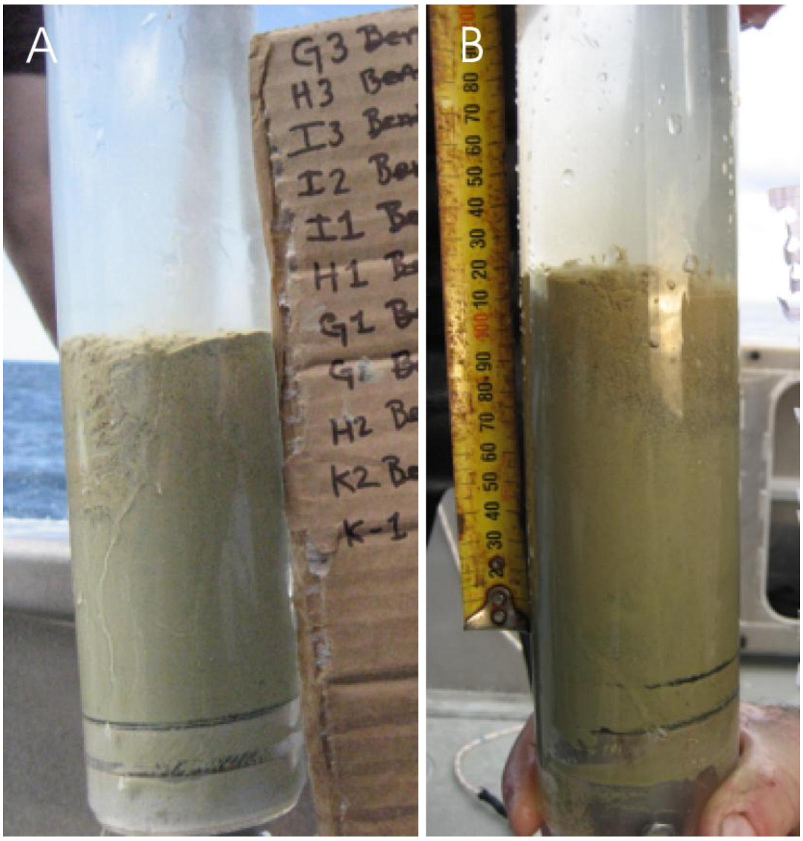
K2



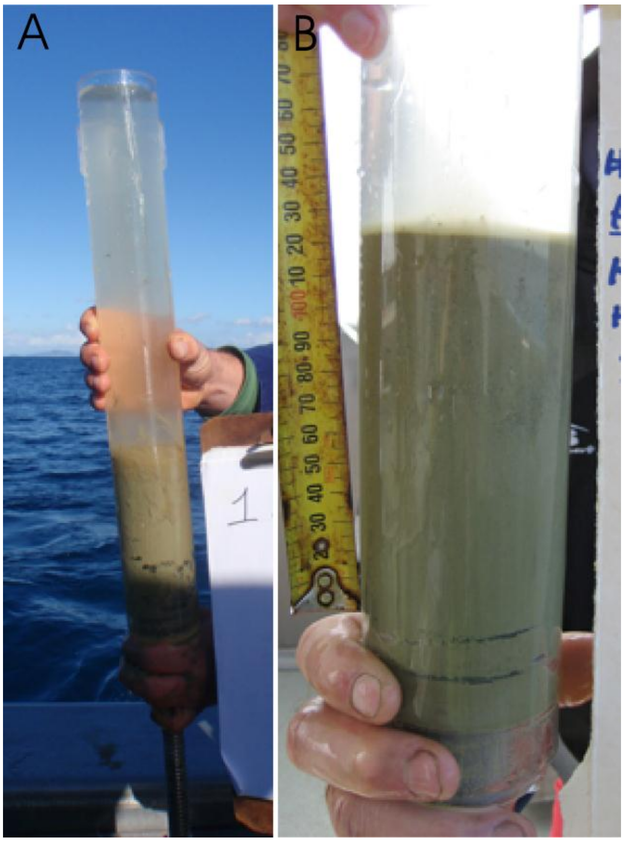
K5



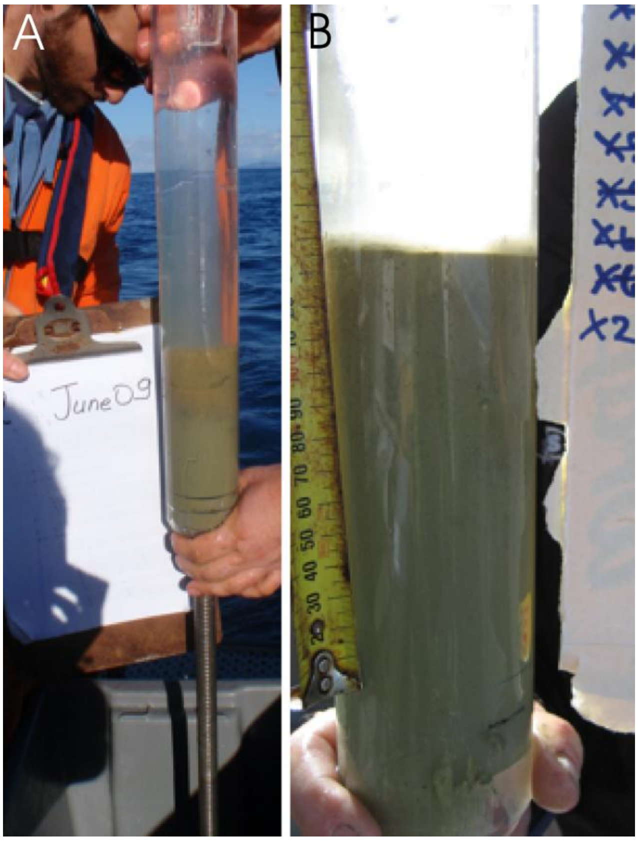
K-1



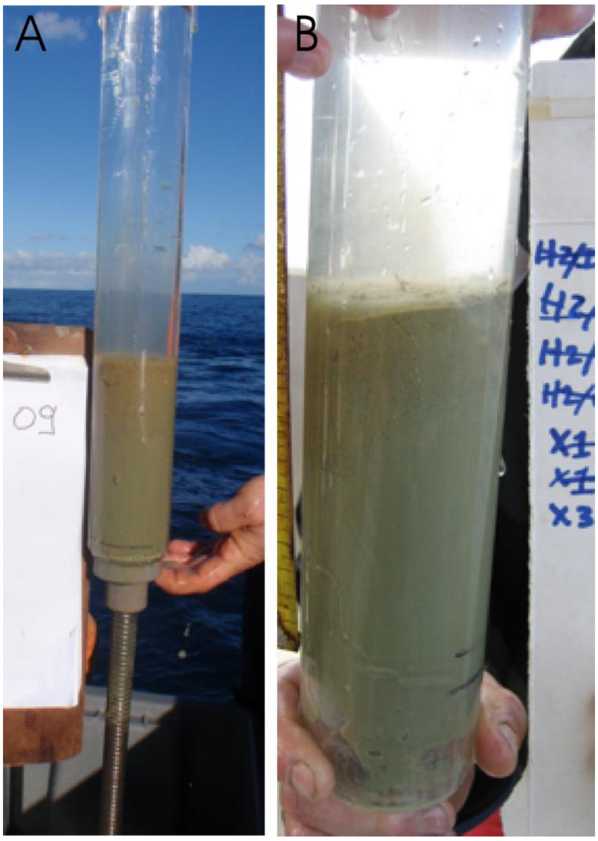
X1



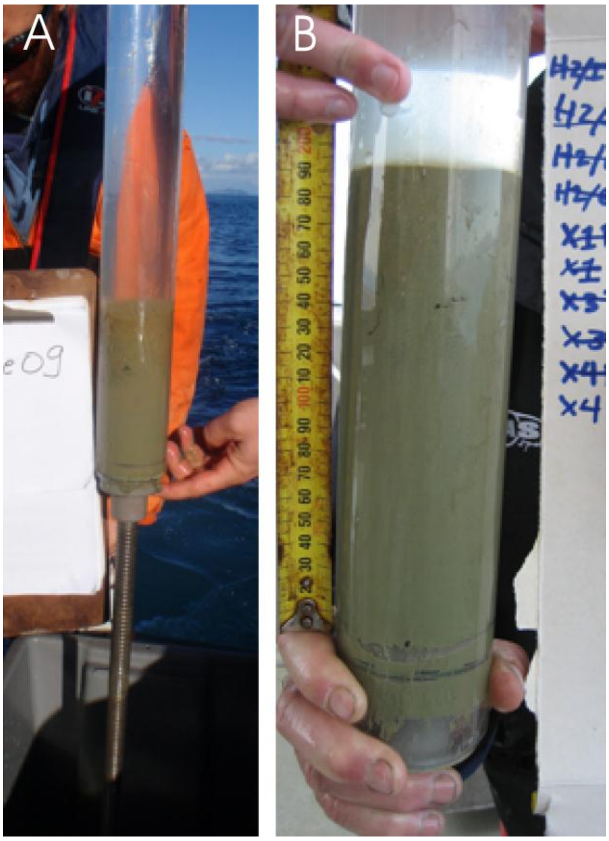
X2



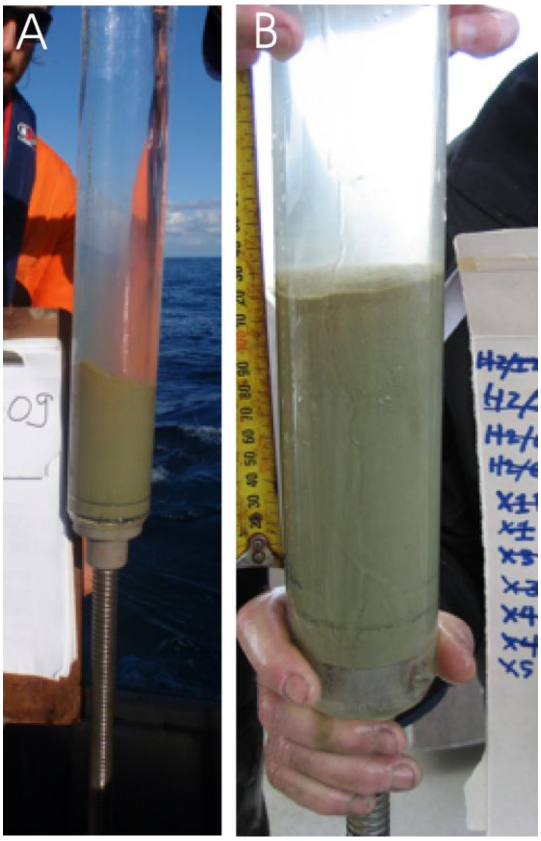
X3



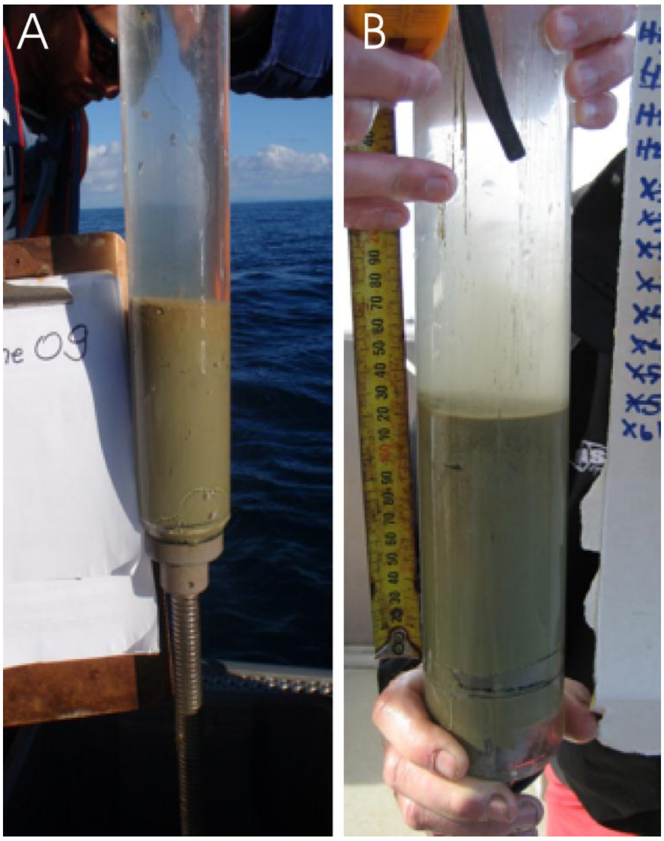
X4



X5



X6

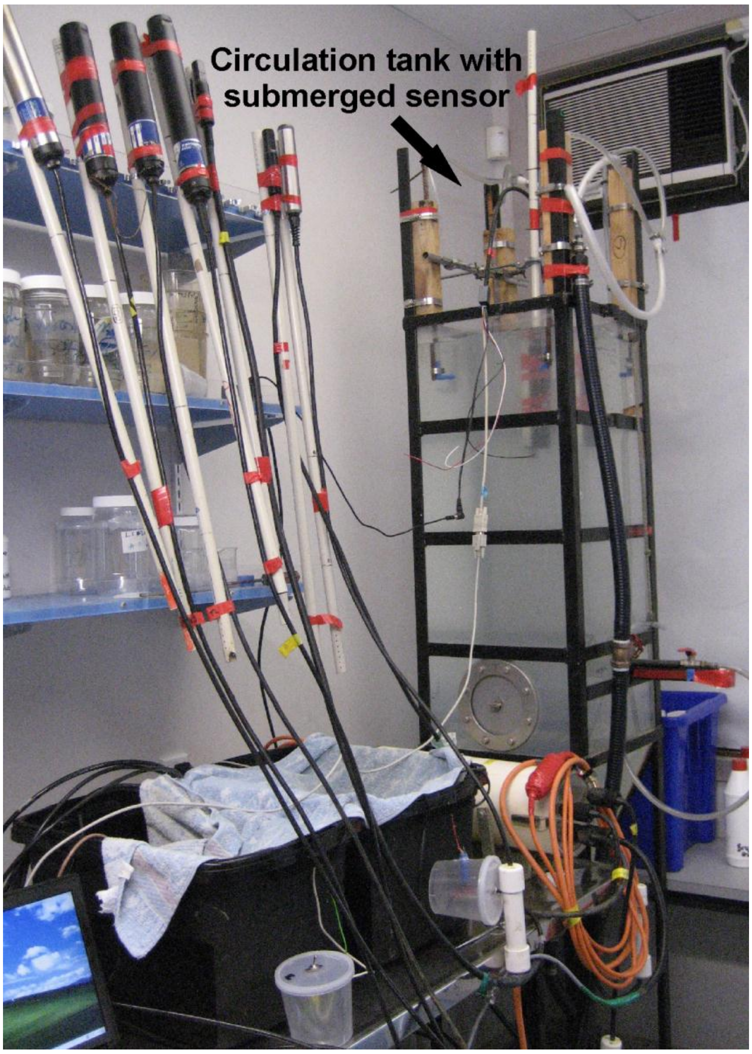


APPENDIX II

Turbidity Sensor Calibration Procedure

Calibrations and Data Scaling

Turbidity sensor calibrations were undertaken prior to the first plume survey to determine scaling factors for converting raw sensor data to the equivalent suspended sediment concentration (SSC) (mg/L). Calibrations were undertaken using a suspended sediment calibration tank (see below) at National Institute of Water and Atmospheric Research (NIWA). Mud slurries composed of sediment collected from the marina basin at Pine Harbour was added to the calibration tank gradually to progressively increase the SSC within the tank. Following each increase in SSC, the tank was allowed to circulate for 15 min before time averaged readings were recorded for each sensor. A 1 litre water sample was collected from the centre of the tank prior to the addition of more slurry. The SSC (mg/L) of each dilution, determined by filtering each 1 litre sample (APHA, 1997), was plotted against the corresponding time-averaged readings for each sensor to establish the scaling factors for each sensor time series recorded during the 4 plume monitoring surveys.



During tests prior to calibration, it was observed that sensor readings varied depending on the station configuration for the same concentration (mg/L) sample (e.g. one sensor attached to the power source and logger compared to 2 sensors). Therefore, during calibrations the sensors were set-up as they would be deployed in the field. In most cases, one logger and power source were connected to 2 sensors.

Specific sensor pairings for each station were also maintained for calibrations as well as field deployments.

The first set of calibration coefficients apply to the station configurations for Surveys 1 and 2. The only change to the configuration for Survey 2 was to dismantle Station D and switch Sensor 8 to Station A at 7 m below the surface as back-up after discovering that a power switch failure had prevented any data collection at that station. It was decided that deploying 4 stations was too labour intensive for the allotted time and with a limited supply of sensors, it was better to ensure that 3 stations collected the maximum amount of data. Sensor 8 used an internal power source and logger so the calibrations undertaken prior to Survey were still applicable to the station configurations used in Survey 1. During the second survey, the sensors on Station B became entangled in the vessel propeller. The cable on Sensor 3 snapped and the sensor was lost. Sensor 4, however, was salvaged with only minimal damage to the cable.

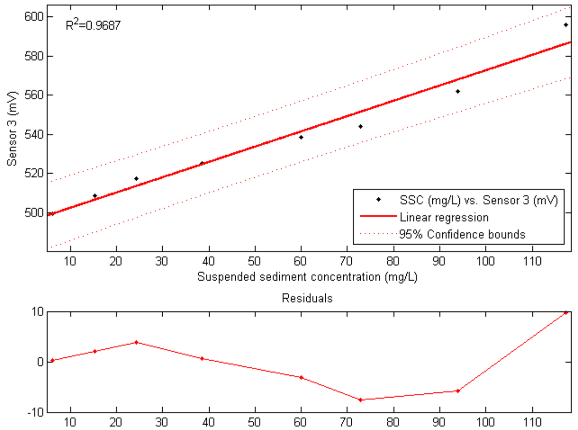
For the third and fourth plume surveys, the stations were reconfigured slightly again as past experience with the first 2 surveys proved that it would be beneficial to add more back-up sensors for insurance against unforeseen circumstances. For Station A, sensor 2 and 1 were shifted to 1 and 5 m below the surface, respectively. They shared the same logger and power source as in the first 2 surveys. Sensor 8 was shifted to 10 m below the surface and Sensor 9 was added at 7 m below the surface. Similar to Sensor 8, Sensor 9 used an internal power source and logger. At Station B, Sensor 7 was added at 5 m below the surface to take the place of Sensor 3. After repair to the cable, Sensor 4 was deployed again at 10 m below the surface. Sensor 7 and 4 shared the same power source and logger. Sensor 10 was added at 7 m below the surface and used its own power source and logger. The configuration for Station C during both the 3rd and 4th surveys remained unchanged from Surveys 1 and 2.

Due to altered station configurations and added sensors in the 3rd and 4th surveys previous calibration values used for Surveys 1 and 2 were no longer valid. Therefore, following completion of the 4th survey, a second set of calibrations, following the same procedure, were undertaken and be applied to the data collected in the last two surveys.

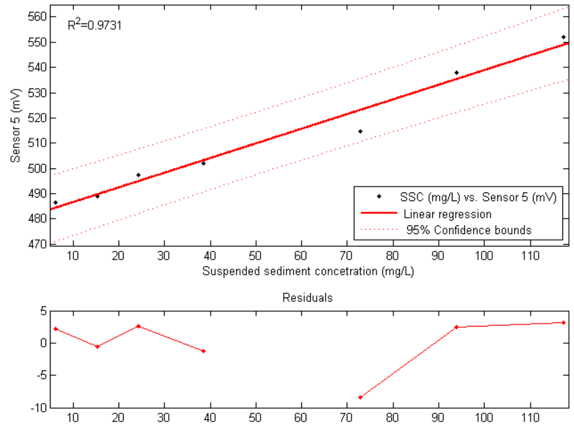
The following plots and accompanying tables show the linear fits and the data values used to derive the scaling factors between SSC (mg/L) and the raw reading for each sensor. Sensors that failed during deployment (See Table 3.4) are not shown.

Calibration 1

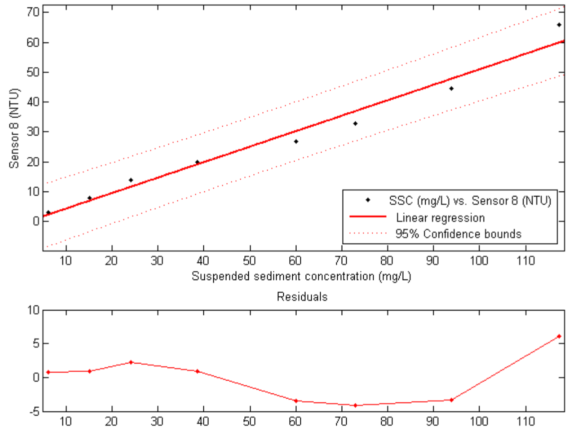
Sensor 3



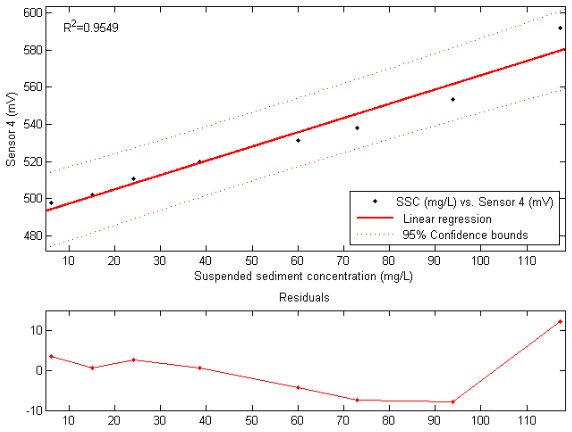
Sensor 5



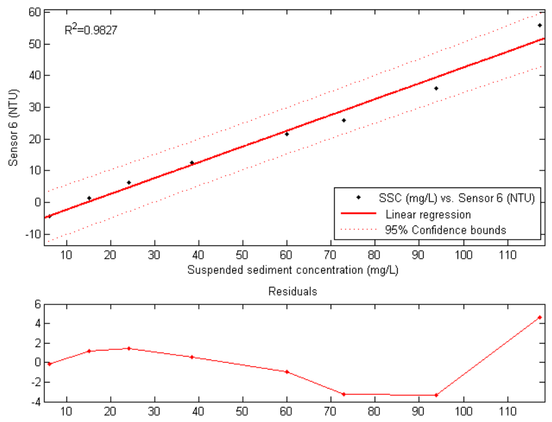
Sensor 8



Sensor 4



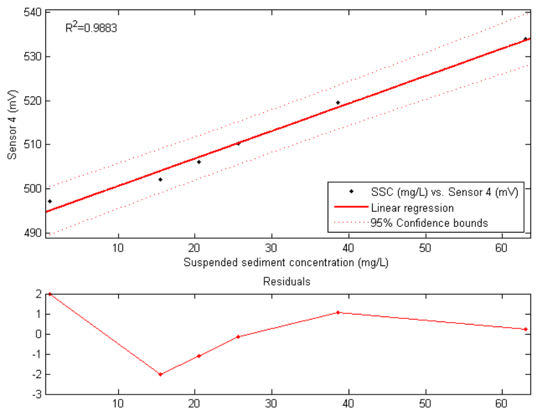
Sensor 6



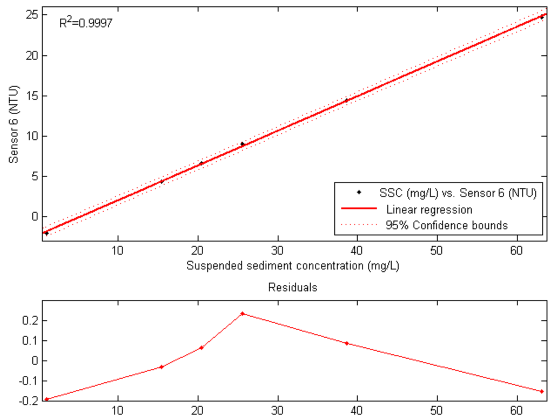
SSC (mg/L)	Sensor 3 (mV)	Sensor 4 (mV)	Sensor 5 (mV)	Sensor 6 (NTU)	Sensor 7 (NTU)
6.16	499.61	497.79	486.60	-4.38	3.16
15.21	508.51	501.97	489.03	1.39	7.92
24.18	517.34	510.80	497.40	6.14	14.00
38.50	525.29	519.81	501.88	12.46	20.05
60.00	538.21	531.34	NaN	21.62	26.74
72.93	543.88	538.13	514.70	25.78	32.84
93.85	562.05	553.59	537.77	36.10	44.40
117.27	595.78	591.63	552.16	55.76	66.01

Calibration 2

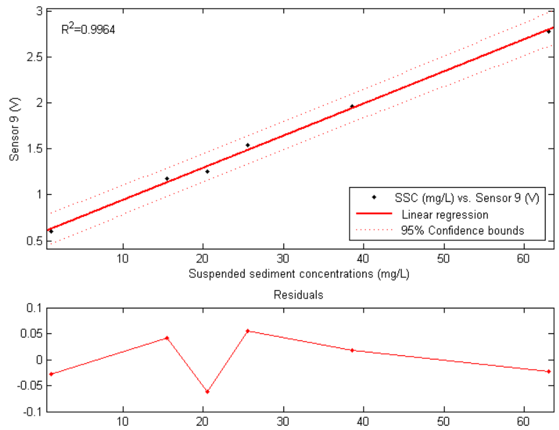
Sensor 4



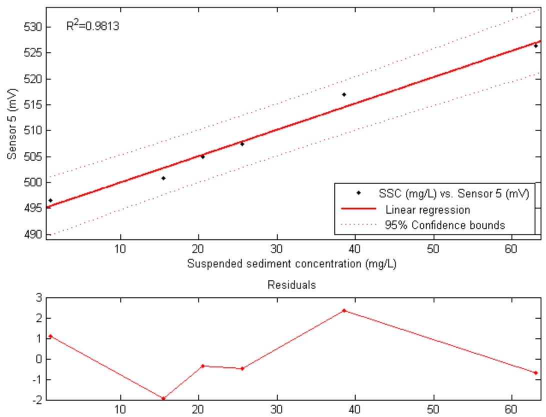
Sensor 6



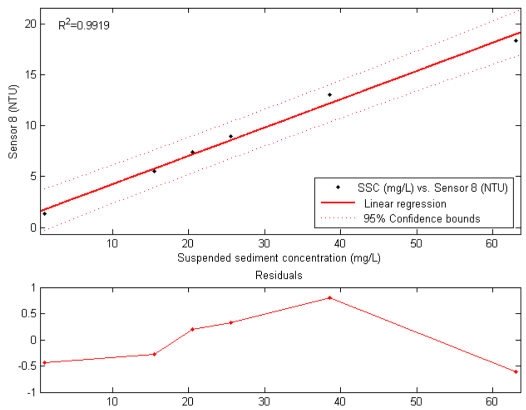
Sensor 9



Sensor 5



Sensor 8



SSC (mg/L)	**Sensor 4 (mV)**	**Sensor 5 (mV)**	**Sensor 6 (NTU)**	**Sensor 8 (NTU)**	**Sensor 9 (V)**
1.11	497.15	496.54	-1.99	1.33	0.60
15.50	502.09	500.86	4.37	5.50	1.18
20.50	506.12	504.97	6.63	7.37	1.25
25.60	510.24	507.43	8.99	8.92	1.54
38.60	519.54	516.90	14.45	13.01	1.96
63.00	533.82	526.30	24.72	18.39	2.78

APPENDIX III

Hill Laboratories

Sediment Chemistry Reports

Hill Laboratories
BETTER TESTING BETTER RESULTS

R J Hill Laboratories Limited
1 Clyde Street
Private Bag 3205
Hamilton 3240, New Zealand

Tel +64 7 858 2000
Fax +64 7 858 2001
Email mail@hill-labs.co.nz
Web www.hill-labs.co.nz

ANALYSIS REPORT

Client:	University of Waikato	**Lab No:**	826328 SPv2
Contact:	Bryna Flaim	**Date Registered:**	13-Sep-2010
	C/- University of Waikato	**Date Reported:**	26-Oct-2010
	Earth Science Department	**Quote No:**	42174
	Private Bag 3105	**Order No:**	220590
	HAMILTON 3240	**Client Reference:**	Elutriation
		Submitted By:	Bryna Flaim

Amended Report

This report replaces an earlier report issued on the 28 Sep 2010 at 2:59 pm
Following a query by the customer the report has been re-issued to correct an error in the reporting of the number of significant figures reported for Total Arsenic, Cadmium and Zinc for the aqueous samples (our reference 826328.7 - 826328.13).

Sample Type: Sediment

Sample Name:		June 2010 G2	June 2010 H2	June 2010 H5	June 2010 I2	June 2010 E2
Lab Number:		826328.1	826328.2	826328.3	826328.4	826328.5
Individual Tests						
Dry Matter	g/100g as rcvd	50	50	51	51	53
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg						
Total Recoverable Arsenic	mg/kg dry wt	2.7	4.0	3.6	3.5	3.2
Total Recoverable Cadmium	mg/kg dry wt	0.165	0.128	0.134	0.131	0.151
Total Recoverable Chromium	mg/kg dry wt	21	22	23	23	22
Total Recoverable Copper	mg/kg dry wt	5.1	24	4.7	4.9	5.0
Total Recoverable Lead	mg/kg dry wt	4.0	6.3	3.9	4.2	4.0
Total Recoverable Mercury	mg/kg dry wt	0.076	0.077	0.056	0.067	0.075
Total Recoverable Nickel	mg/kg dry wt	15.9	14.5	15.5	15.6	16.1
Total Recoverable Zinc	mg/kg dry wt	31	43	31	31	30
Total Petroleum Hydrocarbons in Soil						
C7 - C9	mg/kg dry wt	< 15	< 15	< 15	< 14	< 15
C10 - C14	mg/kg dry wt	< 30	< 30	< 30	< 30	< 30
C15 - C36	mg/kg dry wt	< 60	< 60	< 60	< 60	< 60
Total hydrocarbons (C7 - C36)	mg/kg dry wt	< 110	< 110	< 100	< 100	< 100

Sample Name:		June 2010 X4				
Lab Number:		826328.6				
Individual Tests						
Dry Matter	g/100g as rcvd	46	-	-	-	-
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg						
Total Recoverable Arsenic	mg/kg dry wt	2.5	-	-	-	-
Total Recoverable Cadmium	mg/kg dry wt	0.149	-	-	-	-
Total Recoverable Chromium	mg/kg dry wt	21	-	-	-	-
Total Recoverable Copper	mg/kg dry wt	5.4	-	-	-	-
Total Recoverable Lead	mg/kg dry wt	4.3	-	-	-	-
Total Recoverable Mercury	mg/kg dry wt	0.056	-	-	-	-
Total Recoverable Nickel	mg/kg dry wt	16.3	-	-	-	-
Total Recoverable Zinc	mg/kg dry wt	31	-	-	-	-
Total Petroleum Hydrocarbons in Soil						
C7 - C9	mg/kg dry wt	< 17	-	-	-	-
C10 - C14	mg/kg dry wt	< 40	-	-	-	-
C15 - C36	mg/kg dry wt	< 70	-	-	-	-
Total hydrocarbons (C7 - C36)	mg/kg dry wt	< 120	-	-	-	-

Sample Type: Sediment					
Sample Name:	June 2010 X4				
Lab Number:	826328.6				

Sample Type: Aqueous						
Sample Name:		Seawater for Elutriate 11-Jul-2010	June 2010 G2 (Elutriation Extract)	June 2010 H2 (Elutriation Extract)	June 2010 H5 (Elutriation Extract)	June 2010 I2 (Elutriation Extract)
Lab Number:		826328.7	826328.8	826328.9	826328.10	826328.11
Individual Tests						
Total Arsenic*	g/m³	< 0.0042	< 0.0042	< 0.0042	0.0048	< 0.0042
Total Cadmium*	g/m³	< 0.00021	< 0.00021	< 0.00021	< 0.00021	< 0.00021
Total Chromium*	g/m³	< 0.0011	< 0.0011	< 0.0011	< 0.0011	< 0.0011
Total Copper*	g/m³	< 0.0011	< 0.0011	< 0.0011	< 0.0011	< 0.0011
Total Lead*	g/m³	< 0.0011	< 0.0011	< 0.0011	< 0.0011	< 0.0011
Total Mercury*	g/m³	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008
Total Nickel*	g/m³	0.0092	0.0108	0.0101	0.0087	0.0101
Total Zinc*	g/m³	< 0.0042	< 0.0042	< 0.0042	< 0.0042	< 0.0042

Sample Name:		June 2010 E2 (Elutriation Extract)	June 2010 X4 (Elutriation Extract)			
Lab Number:		826328.12	826328.13			
Individual Tests						
Total Arsenic*	g/m³	0.0047	0.0061	-	-	-
Total Cadmium*	g/m³	0.00021	0.00022	-	-	-
Total Chromium*	g/m³	< 0.0011	< 0.0011	-	-	-
Total Copper*	g/m³	< 0.0011	< 0.0011	-	-	-
Total Lead*	g/m³	< 0.0011	< 0.0011	-	-	-
Total Mercury	g/m³	< 0.00008	< 0.00008	-	-	-
Total Nickel*	g/m³	0.0089	0.065	-	-	-
Total Zinc*	g/m³	< 0.0042	< 0.0042	-	-	-

SUMMARY OF METHODS

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Samples
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction.	-	1-6
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	-	1-6
Elutriation testing*	Extn with (client supplied) water, eg seawater, Sed:Water 1:4 by vol, mix 30 min, settle 1 hr, filt/cent. US EPA 503/8-91/001, "Evaluation of Dredged Material for Ocean Disposal".	-	1-6
Total Petroleum Hydrocarbons in Soil	Sonication extraction in DCM, Silica cleanup, GC-FID analysis US EPA 8015B/MfE Petroleum Industry Guidelines. Tested on as received sample	-	1-6
Dry Matter (Env)	Dried at 103°C (removes 3-5% more water than air dry) for 18hr, gravimetry. US EPA 3550.	0.10 g/100g as rcvd	1-6
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-6

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Samples
Total Digestion of Saline Samples*	Nitric acid digestion. APHA 3030 E 21st ed. 2005.	-	7-13
Total Arsenic*	Nitric acid digestion, ICP-MS with dynamic reaction cell, ultratrace. APHA 3125 B 21st ed. 2005.	0.0042 g/m³	7-13
Total Cadmium*	Nitric acid digestion, ICP-MS, ultratrace level. APHA 3125 B 21st ed. 2005.	0.00021 g/m³	7-13
Total Chromium*	Nitric acid digestion, ICP-MS with dynamic reaction cell, ultratrace. APHA 3125 B 21st ed. 2005.	0.0011 g/m³	7-13
Total Copper*	Nitric acid digestion, ICP-MS with dynamic reaction cell, ultratrace. APHA 3125 B 21st ed. 2005.	0.0011 g/m³	7-13
Total Lead*	Nitric acid digestion, ICP-MS, ultratrace level. APHA 3125 B 21st ed. 2005.	0.0011 g/m³	7-13

Sample Type: Aqueous			
Test	**Method Description**	**Default Detection Limit**	**Samples**
Total Mercury*	Bromine Oxidation followed by Atomic Fluorescence. US EPA Method 245.7, Feb 2005.	0.00008 g/m^3	7-13
Total Nickel*	Nitric acid digestion, ICP-MS, ultratrace level. APHA 3125 B 21st ed. 2005.	0.0063 g/m^3	7-13
Total Zinc*	Nitric acid digestion, ICP-MS with dynamic reaction cell, ultratrace. APHA 3125 B 21st ed. 2005.	0.0042 g/m^3	7-13

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

This report must not be reproduced, except in full, without the written consent of the signatory.

Carole Rodgers-Carroll BA, NZCS
Client Services Manager - Environmental Division