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Monitoring tools for dredging

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MONITORING TOOLS FOR DREDGING

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Key Words

Abstract

The monitoring approach employed for characterisation of sediment discharges and plumes generated during aggregate dredging in the Eastern English Channel is described. Quantification of both overflow spillway losses and screening losses is considered. It is shown that largely standard, "off the shelf" instruments can be used to undertake effective monitoring both around working aggregate dredgers and within their hoppers. The performance of each type of instrument is addressed and sample results are presented.

1   Introduction

By its very nature, dredging, whether capital, maintenance or aggregate, changes the aquatic environment. Where environmental change is induced there is potential for impact, this occurs where receptors exist (usually organisms) which are sensitive to the changes induced by dredging.

Monitoring is one of the two main approaches used to help understand potential environmental impacts associated with dredging (the other being modelling / prediction). It is used routinely to: help plan projects (collection of baseline measurements); control works (monitoring during dredging); to confirm that both short and long term predictions with respect to impact are correct; and to improve predictive capability.

In addition to its importance with respect to meeting legal (regulatory) requirements, monitoring is of commercial importance, protecting contractors and developers against financial claims by those asserting that works have had a negative effect on their livelihoods and /or property.

The form that monitoring takes depends on the purpose and requirements of the study or study component (e.g. whether it is to measure impact at sensitive receiver sites or to validate / refine model outputs).

The present contribution describes the approach used by HR Wallingford to measure screening and overflow discharges from the aggregate dredger *Arco Axe* during typical working scenarios, along with sediment plumes generated from the activity. The monitoring was carried out on behalf of the East Channel Association (ECA) comprising: Britannia Aggregates Ltd; CEMEX UK Marine; DEME Building Materials Ltd, Hanson Aggregates Marine Ltd; Tarmac Marine Dredging Ltd and Volker Dredging Ltd. The development of an instrument array to measure the source term was facilitated through a Marine Aggregate Levy Sustainability Fund (MALSF) funded study undertaken in parallel with the ECA plume monitoring study.

The monitoring was undertaken to help validate impact predictions and forms part of the wider monitoring programme being undertaken during dredging in the eastern English Channel by the ECA (www.eastchannel.info).

2   General approach to monitoring within the East Channel region

Within the East Channel Region 11 dredging permission areas exist (Figure 1). There is a great deal of similarity between the sites in terms of: sedimentology; bathymetry; and the plant to be used for winning cargos. Consequently, the ECAs approach to monitoring at the site is regional in outlook but it also considers issues relating to individual areas as required.
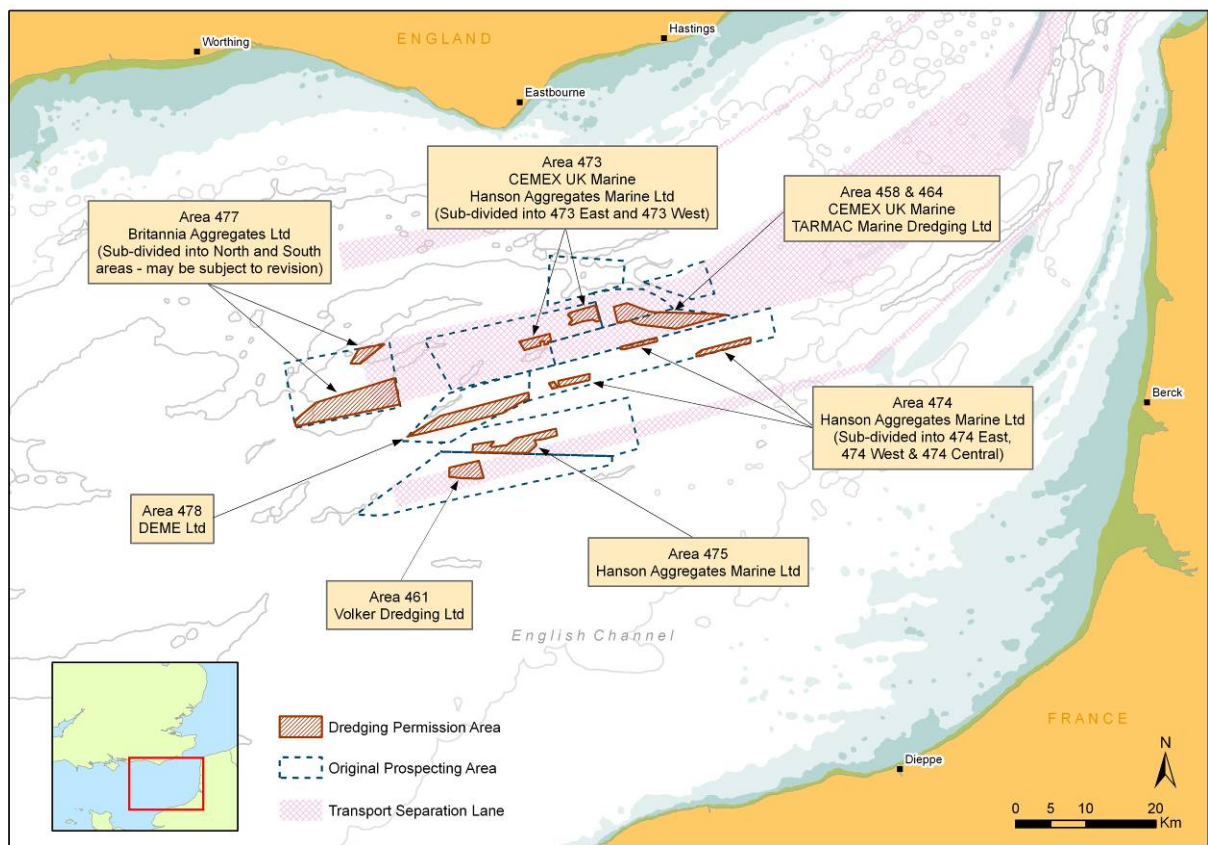

Figure 1   East Channel Region dredging permission areas

For the monitoring of dredger discharges and sediment plumes within the East Channel Region it was necessary for the ECA to identify dredging plant and a licence area that was highly representative of the dredging activities in the region as a whole. The selected vessel was the A-Class trailing suction hopper dredger *Arco Axe* owned and operated by Hanson Aggregates Marine Ltd (Figure 2).

Figure 2 *Arco Axe* **specification sheet.**

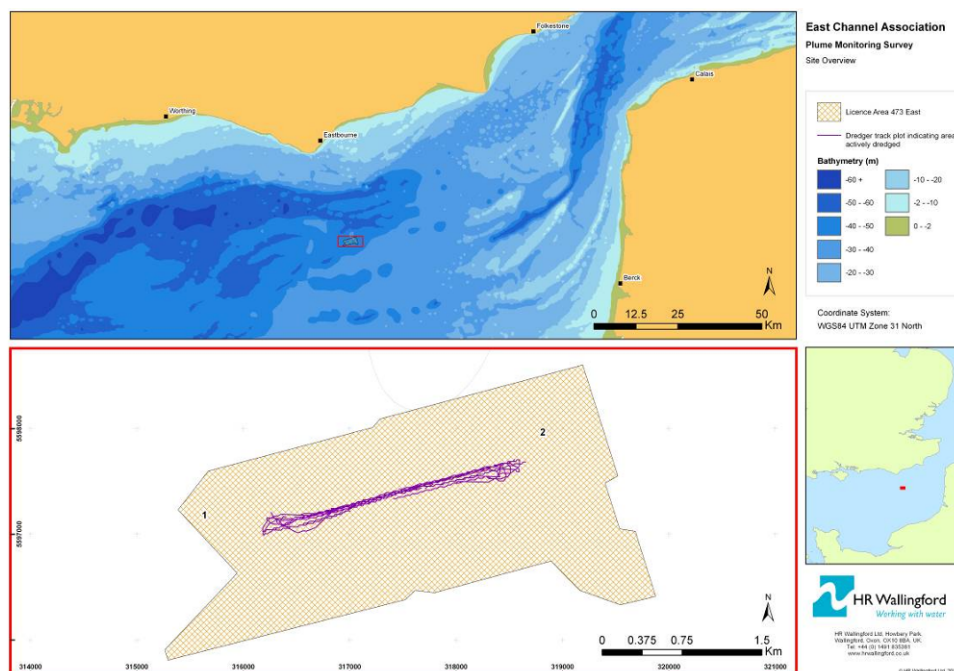The selected dredging permission area was 473 East (Figure 3).

Figure 3 **The study location, Licence Area 473 East**

The bed level at the site was between 40 m and 45 m (chart datum).

As both 'screened' and 'all-in' dredging is licensed in the East Channel Region, monitoring was planned for both types of activity. In the case of a 'screened' load, where the coarse material is to be retained in the hopper, the unwanted fine material falls through the mesh of the steel screens within the screening towers to be rejected back to the sea. In the case of an 'all-in' load (a mixture of fine and coarse material) all of the dredged mixture enters the hopper with none being rejected overboard.

To check that the loads monitored were representative of other cargos won from Area 437 East a programme of sediment sampling and particle size analysis was undertaken. In total, 20 all-in cargos and 20 screened cargos from 5 different vessels were monitored. Samples were collected from the wharf after the dredger had discharged its cargo and sample sizes were approximately 50 kg (as required by BS1377 Part 2). Dry sieving was undertaken at 1 Phi intervals.

3 Monitoring aboard the dredger: Source terms

The monitoring undertaken during the study can broadly be divided into two types: monitoring aboard the dredger and monitoring around the dredger. The purpose of the monitoring aboard the dredger was to measure the quantity and character of sediment discharged overboard and thereby to characterise the source of the sediment plumes (also known as 'source terms').

The development of the instrument array used to measure the source term was facilitated through a Marine Aggregate Levy Sustainability Fund (MALSF) funded study (HR Wallingford, 2009) commissioned by the Marine Environment Protection Fund (MEPF). The MALSF study (MEPF Ref No: MEPF 08/P70) was commissioned in August 2008 and was undertaken in parallel with this ECA funded project.

Discharges overboard from trailing suction hopper aggregate dredgers are of two types: hopper overflow; and screened sediment. In designing monitoring programmes for both types of discharge there were a number of common considerations, these can be summarised as follows.

i. The measurements collected must be as accurate and representative as possible (within the time and budget constraints of the project).
ii. The monitoring must be safe (meet the requirements of UK Health and Safety legislation and those of the vessel operator). A significant limitation being that access to the vessel's deck whilst a cargo is being won is not permitted (other than for highly trained and experienced staff employed by the vessel operator).
iii. The monitoring must not interfere unduly with the commercial operation of the vessel (includes considerations such as the time taken to set up instrumentation and the conditions in which this can safely and successfully be achieved).
iv. The instrumentation / approaches used must be well suited to the harsh operating conditions often experienced when dredging offshore.

3.1 Hopper overflow measurements

Hopper overflow is common to trailer suction hopper dredging of all types (capital dredging, maintenance dredging and aggregate dredging). In the case of the *Arco Axe*, hopper overflow is via four deck-level spillways located fore and aft on the port and starboard side of the vessel (Plate 1).

Plate 1   Position of hopper overflow spillways on port side of *Arco Axe*

Notionally, measuring the quantity and character of sediment discharged from such overflow spillways is relatively simple, it can be done by lowering a sampling container into the flow and collecting the sediment and water mixture discharged in a given time interval. However, the reality is that the flow velocities and volumes are such that this is a difficult and dangerous approach to measurement and the accuracy of data collected in this way can be questionable. Current Health and Safety practices employed in the UK do not allow the collection of samples in this way. Specifically, access to the deck of the vessel during dredging is restricted to the vessel crew. In order to be workable any measurement system to be used by the study was therefore required to be automated or capable of being controlled remotely (i.e. from the vessel's Bridge or accommodation block).

A common approach to quantifying sediment movement in the marine environment (e.g. on beaches or at the seabed) is to have two separate instruments at the same location, one measuring current velocity and the other measuring sediment concentration. In the past, velocity measurements were often undertaken using electromagnetic current meters but, more recently, acoustic Doppler sensors have found favour. Sediment concentration has consistently been measured using optical instruments such as optical backscatter sensors (OBSs), transmissometers and nephelometers. As part of marine monitoring studies such instrumentation is routinely used alongside pressure sensors as these allow accurate measurement of water levels and (in shallow water) wave height. Since such instrumentation is designed for use in the marine environment it can be left unattended to collect measurements and is rugged i.e. in general terms it fulfils two key requirements of instrumentation that might be used for monitoring aboard a dredger.

Given the capabilities and availability of such instrumentation (it can readily be hired at a relatively modest cost) more detailed consideration was given to whether and how it could be used to measure spillway discharges. The theory / concept of using the instrumentation was straightforward. Flux of water could be calculated as the product of the cross-sectional area of the flow (given by the dimensions of the spillway and the water level measured using a pressure

sensor) and the flow velocity (measured using an acoustic Doppler current sensor). The flux of sediment could then be found by multiplication of the water flux by the sediment concentration (from the optical sensor). The practicalities and details of undertaking such measurements were, however, more complex. The following factors were identified at an early stage as potential obstacles to the successful collection of reliable data.

i.   Calibration and measurement range of optical sensors (the pressure sensors and flow meters proposed did not require field calibration).
ii. The potential for bubbles to influence (corrupt) instrument readings.
iii. Instrument mounting position and method.
iv. Protection of the sensors from impact / burial by sediment particles (cargos contain a high proportion of gravel, around 50%).

In order to calibrate optical sensors it is important to collect water samples which can subsequently undergo gravimetric analysis to allow conversion from the instrument's measurement units (formazin turbidity units (FTU) or nephelometric turbidity units (NTU)) to milligrams per litre. The most efficient means of doing this was considered to be the use a self contained (commercially available) carousel water sampler. The unit trialled was an Aquacell P2-Multiform sampler (Plate 2) that could be triggered remotely using a control cable and switch. Laboratory and field testing of the sampler revealed that it was capable of reliably collecting water samples containing very high suspended sediment loads, however, such trials also revealed that the unit required a minor modification to the volume control cylinder to allow it to be reliably used on a platform that was subject to motion. The manufacturer made the necessary modifications.

Plate 2   Aquacell P2-Multiform carousel water sampler

With respect to the choice of optical sensors for the determination of sediment concentration, units available essentially consist of three types: optical backscatter sensors; nephelometers; and transmissometers. The designs of these three types of instrument differ in terms of the relative

position of the light source and the detector. For the purposes of the present study there were three major considerations with respect to the choice of instrument:

- susceptibility to error due to the presence of bubbles in the water should be minimised;
- instruments should, ideally, be capable of reliably detecting a range of particle sizes (silt and sand); and
- the instruments must have a large enough range to allow them to measure the suspended sediment concentrations that are likely to be encountered.

Based on the findings of a desk study and the experience of the authors it was considered that all three types of sensor had the potential to yield erroneous results where bubble concentrations were high and variable. Similarly, OBSs were known to be far more sensitive (by approximately an order of magnitude) to fine grained sediment (silt) than to coarser sediment (sand). With respect to measurement range it was judged that of the instruments available transmissometers had the larger range, giving them an advantage. Overall, confidence in the use of optical sensors in the challenging conditions within the hopper was relatively low. However, it was considered worthwhile to deploy both OBS's and transmissometers as the instruments were judged to have at least a reasonable chance of providing valuable measurements of silt concentrations within the overflow mixture. It was recognised that the results of the water sampling (notionally for calibration purposes but also potentially a measurement tool in itself) would provide clear evidence of the reliability or otherwise of the results from the optical sensors.

Like optical instruments, it was recognised that acoustic current meters have the potential to be influenced by the presence of bubbles in the water column. Despite this both instrument types have routinely and successfully been used in shallow water conditions on beaches where bubbles are known to exist. Given the successful use of acoustic Doppler current meters in such environments it was judged that there was potential for the instruments to yield valuable data when deployed within a dredger spillway. As a check on the validity of the data returned it was proposed to use flow and mixture density measurements yielded by the vessel's installed (standard) sensors.

From a visit to the vessel upon which the measurements were to be undertaken the optimum mounting position for the instrumentation was identified as being within the hopper, directly inboard of the spillway opening with the instruments being mounted upon a frame attached to the hopper coaming (Plate 3).

Plate 3   **Spillway opening within the hopper (location at which it was proposed that measurements were made) and hopper coaming, on which it was proposed that the instrument frame would be mounted**

In determining what level of protection could or should be provided to individual sensors there were three main considerations: how rugged was the sensor; what conditions was the sensor likely to encounter during the measurement programme and could protection be afforded to the sensor without compromising the measurements it was being used to collect. It was judged that there was a high likelihood of the sensors coming into contact with mobile gravel clasts within the hopper, particularly towards the end of the load at which time sediment levels could be at or above the height of the sensors. Damage to the instruments was therefore judged to be a significant concern. All of the sensors identified for potential use were assessed to be rugged, however, only the pressure sensor was considered to be capable of withstanding sustained impacts from gravel clasts without some sort of protection. Consequently it was decided to afford the maximum level of protection possible to the optical sensors and the acoustic current meter. The OBS and transmissometer were therefore protected in purpose built steel shrouds (see Plate 4).

Plate 4   Optical backscatter sensor (left) and transmissometer (right) housed in purpose built protective steel housings

In the case of the acoustic Doppler current meter it was not possible to identify a protective shroud design that would not have the potential to affect the measurements collected by the instrument. As a result it was decided that there was little choice other than to deploy the instrument without a protective housing.

The final instrument array deployed at the aft spillway on the port side of the vessel is shown in Plate 5.
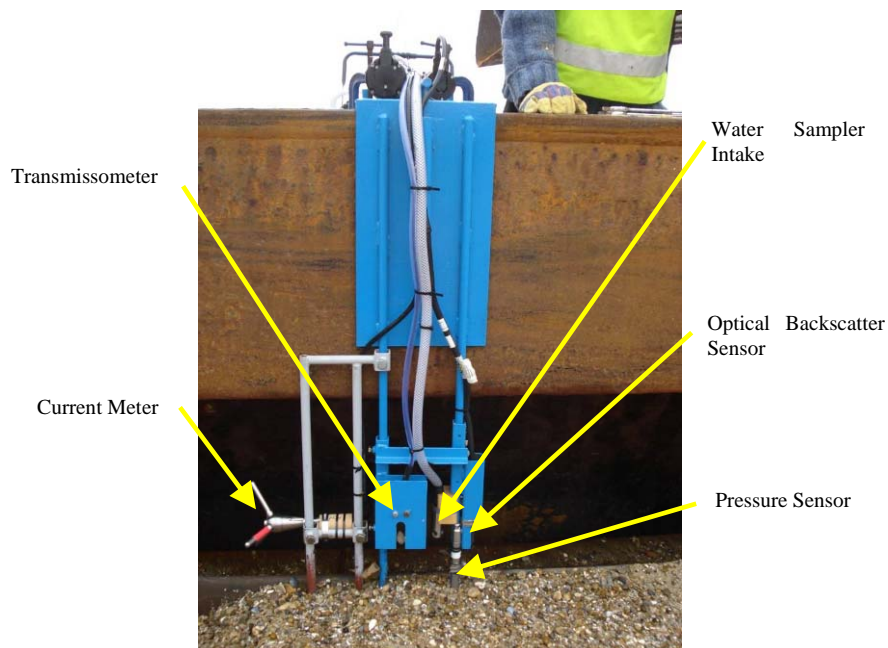
Plate 5   Monitoring instrumentation deployed within the dredger's hopper adjacent to one of the three overflow spillways at which measurements were collected (port aft spillway)

A summary of the overall suite of instrumentation deployed aboard the dredger is presented in Table 1.

Table 1 **Summary information relating to instrumentation used for the measurement of hopper overflow via the vessel's spillways**

Instrument	Sampling Frequency	Deployment Location			
		Aft Spillway Port Side	Forward Spillway Port Side	Aft Spillway Starboard Side	Forward Spillway Starboard Side
Acoustic Doppler Current Meter (Nortek Vector ADV)	8Hz	✓	✗	✗	✗
Optical Backscatter Sensor (Aquatec AQUAlogger 210)	1Hz	✓	✗	✓	✓
Transmissometer (Partech IR15 0-10,000 mg/L)	0.5Hz	✓	✗	✓	✓
Pressure sensor (Level TROLL 500) *	0.5Hz	✓	✗	✓	✓
Carousel Water Sampler (Aquacell P2-Multiform)	Manually triggered	✓	✗	✓	✓

* The sensor was not "vented" therefore it was necessary to simultaneously measure atmospheric pressure, this was done using a Baro TROLL instrument manufactured by the same supplier as that for the pressure sensor (in-Situ Inc).

It can be seen from Table 1 that no instrumentation was deployed at the forward spillway on the port side of the vessel. This was because of significant leakage from the screening tower positioned above this location which would have represented a significant risk to any electronic instrumentation deployed beneath it. The absence of instrumentation at this location was not considered a significant limitation as the suite of sensors deployed at the other three spillways would allow reliable estimates of losses from this spillway to be derived.

An acoustic Doppler current meter was only deployed at one of the four spillways (the aft spillway on the port side of the vessel). This was on the basis that it was considered highly likely that there was a direct relationship between water level at each of the spillways and discharge (flux of sediment and water mixture). It was only necessary to deploy a current meter at one of the four spillways to check that this assumption was correct and to derive the stage discharge relationship.

3.2   Measurement of screening losses

It was recognised at an early stage of the project that direct measurement of screening losses would be problematic due to the nature of the high discharge velocities, shallow water depths encountered within the discharge chutes (Plate 6) and the significant health and safety issues associated with the moving screening towers. For this reason it was decided that the mass of material being lost via the screening towers should be deduced by a combination of other methods, these are set out below.
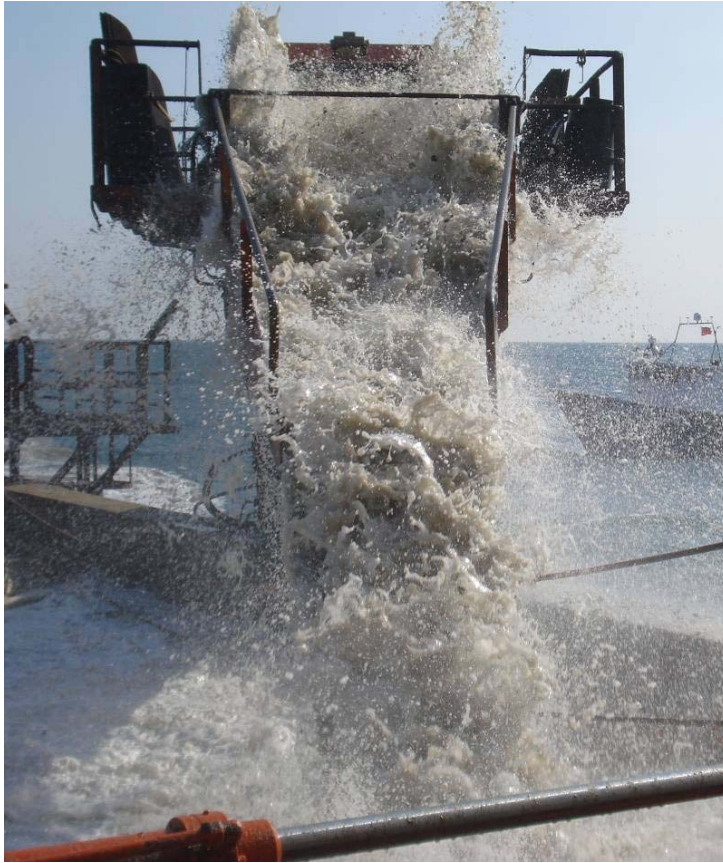
Plate 6   **Forward screening tower aboard the** *Arco Axe*

3.2.1   *Approach I: Rates Approach*

The first approach was to involve calculating the difference between the loading rates (kg/s) for "screened" and "all-in" (i.e. un-screened) cargos and attributing this difference to the loss of sediment via screening. Having calculated the rate difference this was to be multiplied by the loading time for the cargo to provide an estimate of the total mass of sediment discharged via screening for the load. The approach assumes:

- that overflow losses are similar for the two cargos (this could be checked using the proposed measurements within the spillways); and
- that dredger performance in terms of flux of sediment from the seabed remains approximately the same for all-in and screened loads.

From liaison with the vessel's owner and operator (Hanson Aggregates Marine Ltd) in advance of the works it was considered that the dredger performance with respect to flux from the bed should be very similar for the two load types. No difference in dredge pump performance or operation of the vessel (such as opening and closing vacuum values on the draghead) was anticipated. It was known that a check on this assumption could be made using data from the existing suction pipe flow velocity and mixture density meter instruments installed on board the dredger but that there were limitations associated with such checks, namely:

- the analogue data displays for the sensors in question were difficult to read accurately given that indicator needle fluctuations were large in magnitude and of high frequency;

- the instruments (part of the vessel's standard equipment) were overdue for replacement / calibration at the time of the study and as a consequence there was a possibility that their readings were inaccurate: the magnitude of any such inaccuracy being unknown.

In order to provide a measure of the quality of the velocity and mixture density measurements it was recognised that a check could, in turn, be undertaken on these. For the all-in load the quantity of sediment brought aboard the vessel could be calculated from measurements of the amount of sediment remaining within the hopper at the end of the load (derived from the vessel's displacement sensors) and the measured discharges through the spillways. This quantity could be compared against flux measurements calculated from the on-board velocity and mixture density instruments to give a measure of their combined accuracy.

3.2.2   Approach II: Budget Approach

The second approach involved calculating estimates for the following parameters:

- the mass of sediment pumped aboard the dredger during the load, using the measured velocity and mixture density within the dredge pipe (as noted above, for Approach I, there was potential for error in this value);
- the mass of sediment lost from the dredger via the overflow spillways during the load; and
- the mass of sediment left within the hopper at the end of the load (measured using the vessel's displacement sensors).

The estimated mass of material discharged via screening during the load could then be calculated as follows:

Estimated Total Mass of Sediment Discharged via Screening	=	Total Mass of Sediment Pumped Aboard	-	Total Mass of Sediment Lost via Overflow Spillways	-	Mass of Sediment Remaining in the Hopper

Equation 1 Equation for estimation of the mass of sediment discharged via screening

3.2.3   Approach III: Reversed Screening Towers Approach

Given the potential for the flow velocity and mixture density instruments within the dredge suction pipe to provide inaccurate measurements and given the knowledge that such inaccuracy could affect the value of the data provided via Approaches I and II, it was considered that a third approach to the measurement of screening losses should be available and that this should be independent of the measurements made in the dredge suction pipe. Through discussion with Hanson Aggregates Marine Ltd and the East Channel Association, the method agreed involved reversing the screening towers (turning them through 180 degrees) towards the end of a screened load and loading into the hopper approximately 1 m depth of the sediment that would usually have been rejected overboard. Prior to reversing the screening towers, measurements of the level of screened sediment within the hopper were made (12 measurements: 4 transects along the length of the hopper, each with 3 measurement points across the hopper). Similar measurements were made once loading with the screening towers reversed was complete (same positions). From these two sets of measurements the volume (and consequently mass) of sediment loaded with the towers reversed could be calculated. It was planned to check on this measurement using the displacement data recorded aboard the vessel.

4   Monitoring Around the Dredger

The purpose of the monitoring around the dredger was to provide an understanding of the character and extent of the sediment plumes generated by the *Arco Axe* during the period that overflow and screening loses were being monitored. Primarily two approaches were used: a vessel mounted Acoustic Doppler Current Profiler (ADCP) survey (employing the Sediview technique) and plume detection using a multibeam sonar system (MBSS). Both techniques are acoustic and employ instrumentation which was originally designed for another purpose, ADCPs to measure current velocities and MBSSs for bathymetric surveys.

Plume measurement using ADCPs is well documented with the Sediview technique (Land and Jones, 2001) being widely used. In contrast the use of MBSS to monitor sediment plumes is relatively unknown. Simmons et al. (2008) describe measurements in fluvial environments and in a large test tank but the present study is believed to be the first to employ MBSS for the purpose of monitoring sediment plumes around a working dredger.

4.1   Near-field Measurements

Close to the dredger (within ~500 m) a knowledge of the position of the sediment plume relative to the vessel and its extent / form were considered to be the most important factors to determine during the study. If it was also possible to gain some information with respect to the relative intensity of a plume over its spatial extent it was recognised that this would also be advantageous (although it was not judged to be essential).

Based on theoretical and practical considerations, use of MBSS to monitor sediment plumes was considered to have several potentially important advantages over ADCP surveys. These advantages included coverage of a greater area of the water column and the ability to collect valid measurements considerably closer to the seabed, where highest sediment concentrations are often expected to occur. As the technique was new (and based on previous experience with ADCPs) it was accepted that the backscatter from the multibeam could not readily be calibrated in order to yield suspended sediment concentration measurements, this was a disadvantage relative to the use of ADCP.

Given the objectives of the study with respect to the measurement of plumes in the near-field (within ~500 m of the dredger) and the capabilities of the MBSS it was decided to use MBSS for measurements close to the dredger.

The sonar system selected for the investigation was a Reson Seabat 7125 with a single 400 kHz head; this was due to the flexibility the instrument allowed with respect to settings. Attitude and motion were measured with a Coda F180 system and these data were fed into QINSy 8 acquisition, navigation and processing software. The sonar head was mounted on the keel of the survey vessel prior to the main programme of work commencing. The head was at a water depth of 2.6 m and was orientated (rotated 26 degrees to starboard) such that the starboard margin of the swath was parallel to the water surface. The head was deployed in this novel way to allow the instrument to collect measurements to starboard of the survey vessel and beneath it. The swath angle was 128 degrees with each of the 256 beams having an across-track receive width of half a degree; the full water depth (beneath the head) was covered.

High gain (60 dB) and low transmission power (198 dB) settings on the MBSS were used to provide the best detection of the sediment plume within the water column.

During the study, the general approach used was to sail transects through the plume, approximately at right angles to the dredger's track. Such transects were sailed at a range of distances astern of the *Arco Axe* (generally up to a maximum distance of ~500 m astern). Passes

very close to the dredger's stern were also routinely made, within ~70 m. During the sailing of such transects, pumped water samples were collected from a depth of 2 m below the water surface.

The purpose of the water sampling was to assist with the interpretation of data collected in the upper water column. It was thought that bubbles might occur close to the sea surface resulting in high backscatter being measured in this zone without high sediment concentrations necessarily being present.

In addition to running transects approximately at right angles to the track of the dredger, periodically, transects were run parallel to the dredger's track (longitudinal transects).

Data were recorded in Reson .s7k proprietary format and in Windows Media Player files for ease of viewing.

4.2   Far-field Measurements

The downward facing Acoustic Doppler Current Profiler (ADCP) used for the study was an RDI 300 kHz Sentinel Workhorse. This was deployed on a rigid frame 1 m below the sea surface. The Sediview technique requires data on the water temperature and salinity over the water depth and the ADCP requires calibration using suspended solids concentration and particle size data obtained from the analysis of water samples. As a result, a Rapid Drop Profiler (RDP) was employed during the study (Plate 7). This essentially consisted of a combined multiparameter sonde and a three-channel water sampler (the latter having the capability to be fired on demand).
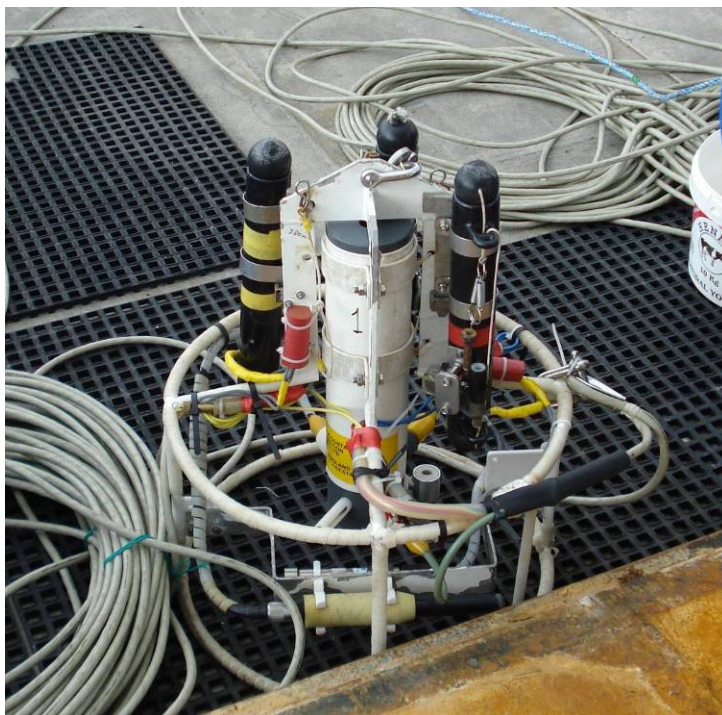

Plate 7   Rapid Drop Profiler (RDP)

When the dredger was working, the survey vessel would first approach the dredger (to within ~500 m) and a float with a drogue attached approximately 20 m below the float was released in the centre of the visible sediment plume. The purpose of the float was to mark the centre of the plume as it was transported and dispersed by the tidal currents and so give the survey vessel a clear marker of the plume's location. After releasing the float, the survey vessel then sailed

repeated transects perpendicular to the tidal currents passing as closely as possible to the float while recording the ADCP data. The transects were repeated until the sediment plume could no longer be detected from the real time inspection of the ADCP backscatter data. Once the plume had dispersed, the float was retrieved and re-released behind the dredger and the whole procedure was then repeated. At frequent intervals during the transect monitoring, the survey vessel would stop within the plume and, while drifting with the tidal currents, the RDP and water sampler were deployed to obtain the temperature, salinity, turbidity data and to collect water samples at three selected levels over the water depth depending on the position of the plume.

4.3   Hydrodynamic Measurements

In order to understand the forcing mechanisms influencing the development of sediment plumes generated during the study two Eulerian moorings were deployed. Each mooring included a seabed frame upon which an upward-looking 600 KHz Nortek Acoustic Wave and Current meter (AWAC) with Acoustic Surface Tracking (AST) was deployed. The moorings were located at the western (Frame 1) and eastern (Frame 2) ends of the Area 473 East resource region approximately 3300 m apart. The mooring locations are shown on Figure 3.

The parameters measured by the AWACs were:

- current velocity (profiled through the water column);
- current direction (profiled through the water column);
- wave height;
- wave period;
- wave direction; and
- water level.

5   Results

The performance of the monitoring approaches that are the focus of the present contribution is described in the following sections. Sample instrument data are presented where appropriate.

5.1   Hopper overflow measurements

The P2-Multiform carousel water samplers were triggered 205 times during the three days of monitoring and 181 samples (88%) were successfully collected. Almost all of the failures to collect a sample occurred during the first day of monitoring and were due to one of the instruments not having had its volume control cylinder modified (extended volume probes were not fitted), this was an oversight on the part of the instrument manufacturer and was quickly overcome. On the very small number of other occasions that samples were not collected it was found that this was due to the trim of the vessel resulting in the inlet hose not being submerged.

As described previously, one of the purposes of the collection of water samples was for the calibration of the OBSs and transmissometers deployed. The calibration data (including some collected during MALSF trialling of the instrument suite) are presented in Figures 4 to 7.
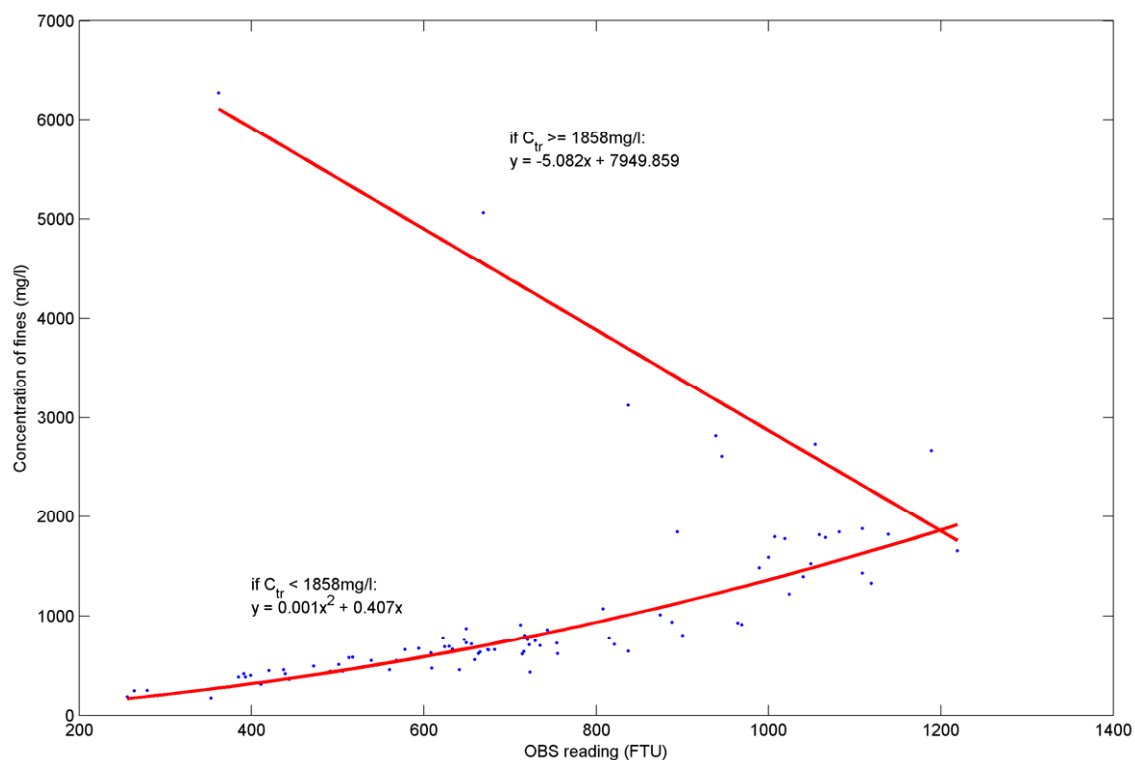
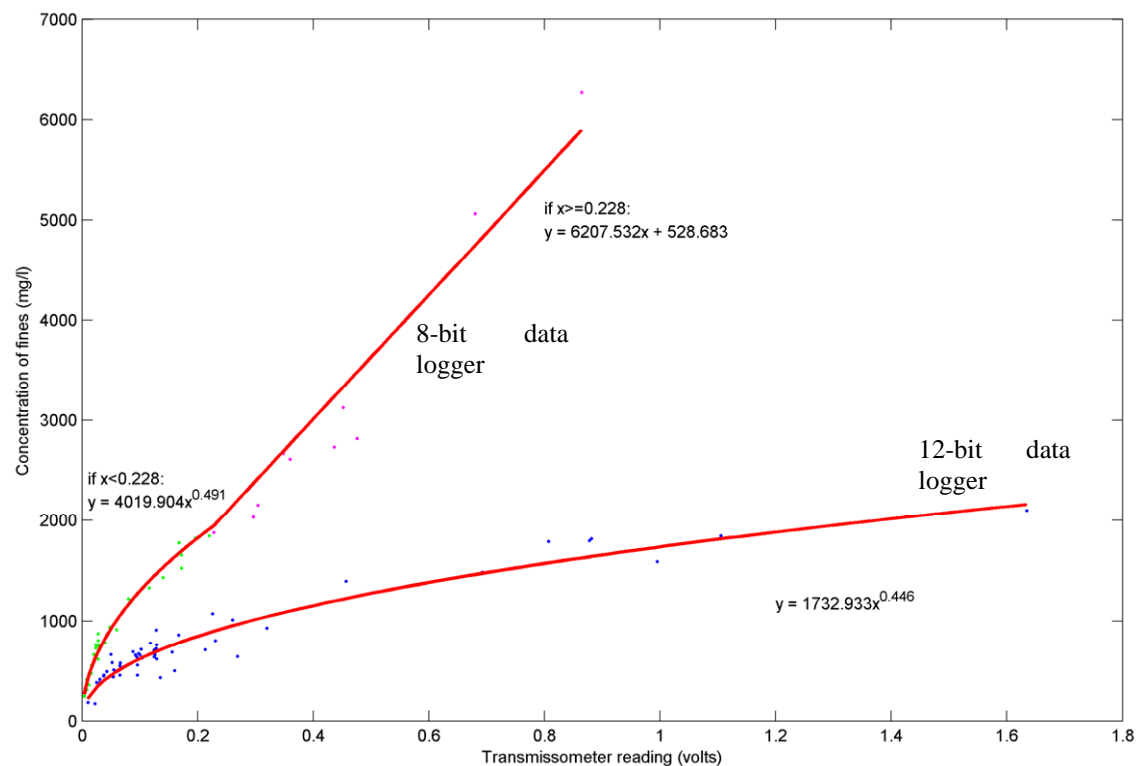**Figure 4   Silt calibration applied to OBS (AQUAlogger 210) data**

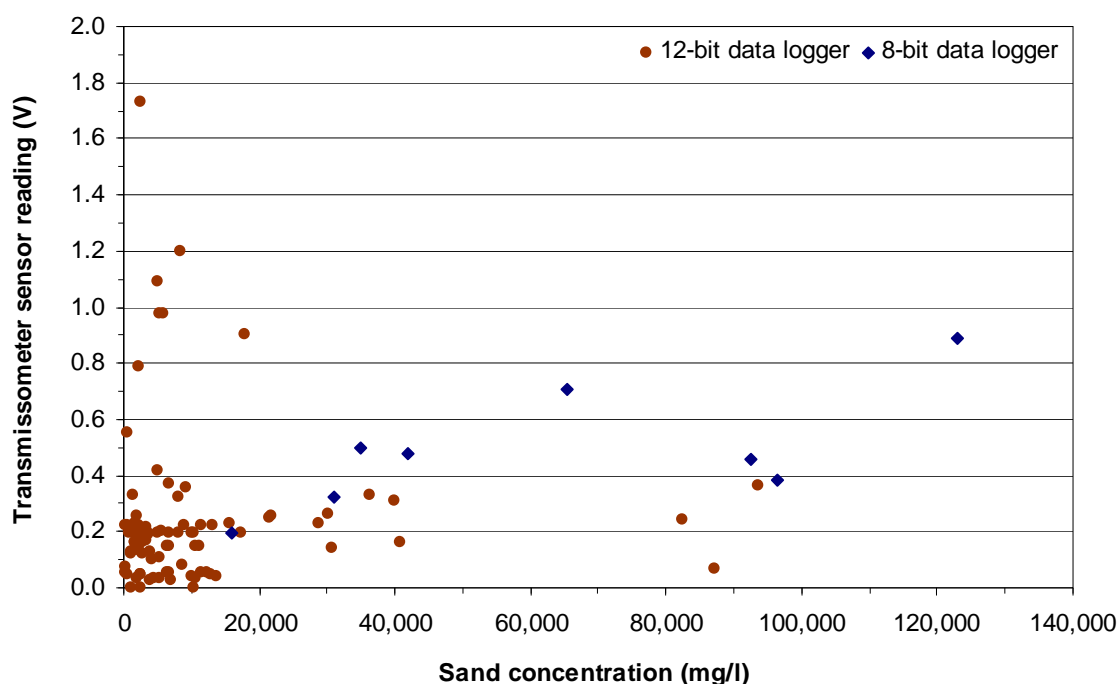**Figure 5   Silt calibration applied to transmissometer (Partech IR15) data**

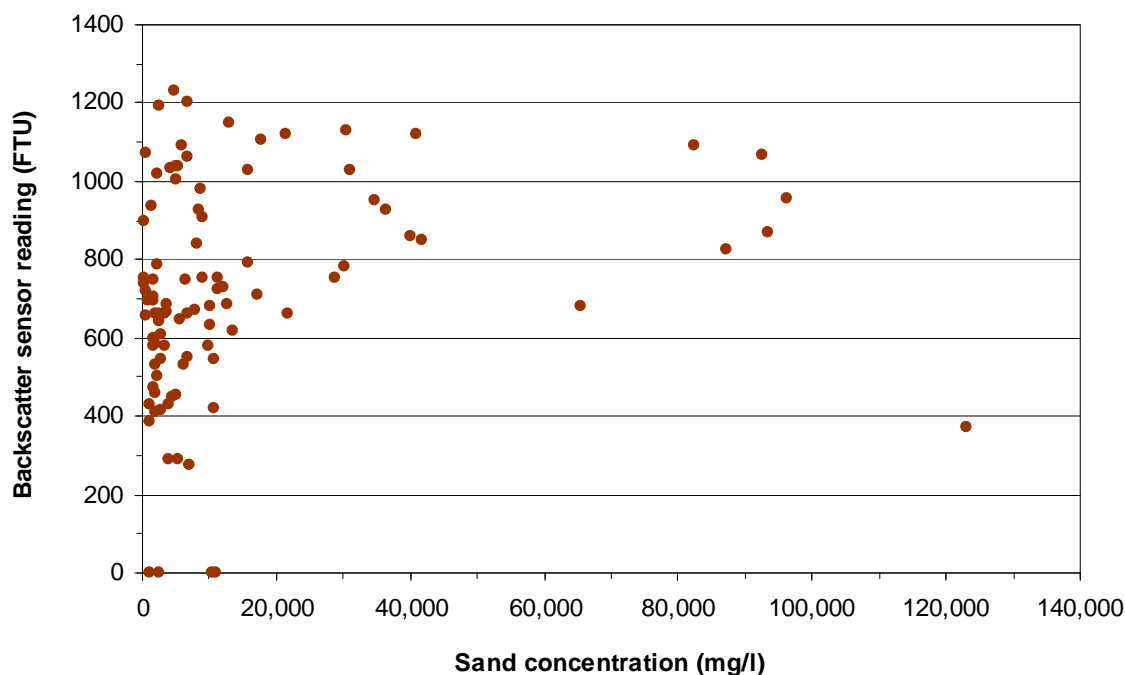**Figure 6**   **Sand calibration data for the transmissometer sensors**

Figure 7   **Sand calibration data for the OBS sensors**

As can be seen, valid calibrations were achieved for both types of sensor against the concentration of silt (material with a particle size <63 microns) within the water samples, whereas calibration against sand concentration (and, in fact, concentration of sand and silt combined) was not possible. This was not considered a significant limitation to the study as sand

concentration passing through the spillways could be derived directly from the water sample data.

Sample timeseries data illustrating results from the transmissometer, OBS and water sampling are presented in Figure 8.
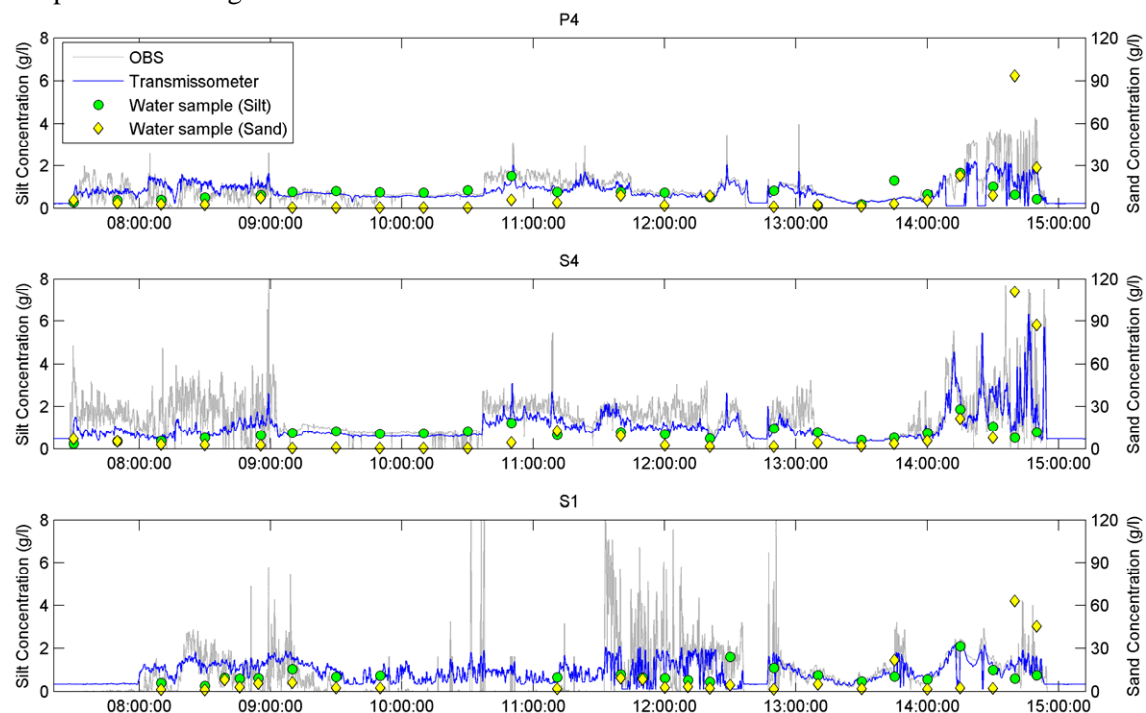
Figure 8   **Water sample results and measured silt concentrations (via both OBS and transmissometer) at the port aft (P4), starboard aft (S4) and starboard forward (S1) spillways during the screened load monitored**

In general, it was found that the data from the OBSs contained more spikes and readings were higher than those of the transmissometers. This was particularly noticeable during periods when the screening towers were directed towards a particular spillway resulting in the sensors encountering more bubbles. Both sensor types delivered full datasets throughout the study, although on a few occasions the transmissometer did measure over-scale.

The position of the screening towers was also found to have a noticeable effect on both the velocity and the water level measurements. From Figure 9 it is apparent that at the start of the load when the aft screening tower was directed towards the port aft spillway both the velocity and water level measurements showed a high degree of variability. Such variability is not present towards the middle of the record when the when the aft screening tower was directed forward away from the instruments. At times when the data with increased variability exists it is found that the running average of the measurements is consistent with that recorded at other times suggesting that the readings were not significantly compromised for the purposes of the present study. All water level and velocity measurement instruments recorded full datasets during the three day study.
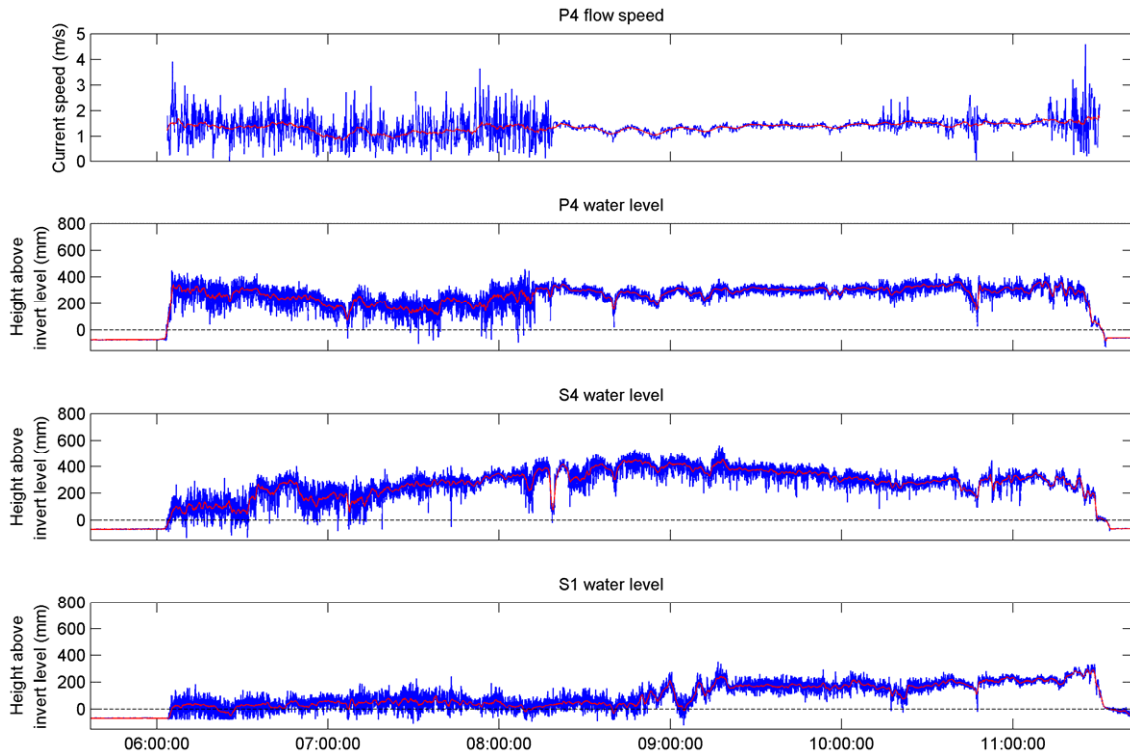
Figure 9 **Timeseries of current speed measured at the port aft (P4) spillway and water level recorded at the port aft (P4), starboard aft (S4) and starboard forward (S1) spillways during the monitored all-in load**

Based on all of the velocity and water level data collected at the port aft spillway (along with a knowledge of the dimensions of the manifold) a stage discharge curve was derived, this is presented in Figure 10.
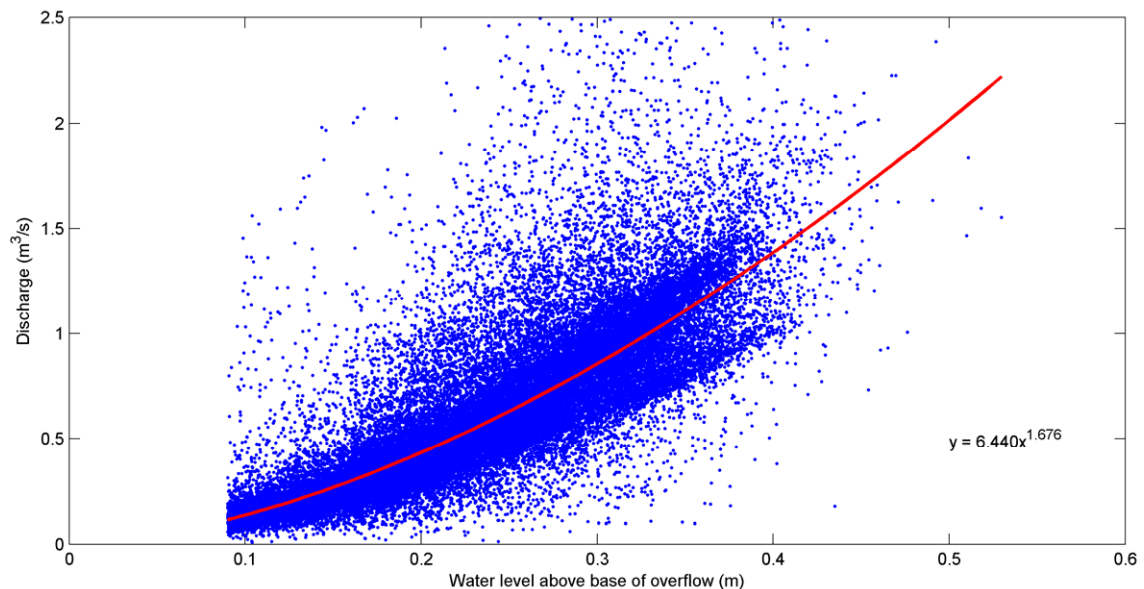

$$y = 6.440x^{1.676}$$

Figure 10 **Stage discharge curve derived from measurements made at the port aft spillway**

5.2   Measurement of Screening Losses

Consideration of sediment fluxes measured within the suction pipe (via the vessel's own sensors) during the screened and all-in loads revealed significant differences. The average flux for the all-in load was 541 kg/s whilst that for the screened load was 818 kg/s. When multiplied by the duration of a load such differences are very large. Given that two of the three approaches for calculating screening losses required knowledge of these quantities (or assumptions to be made about them) it was decided to check the validity of the value derived for the all-in load.

Multiplying the average suction pipe flux measured (using the vessel's own sensors) during the all-in cargo by the duration of the load yielded an estimate of the total quantity of sediment brought aboard the vessel. Comparison of this value against the (measured) total mass of sediment retained in the hopper and the (measured) quantity of sediment discharged via the overflow spillways during the all-in load revealed a disparity of 70%. This finding strongly indicated that the sediment fluxes derived using the vessel's own sensors within the suction pipe were unreliable. As a consequence, it was decided that the Budget Approach to calculating screening losses should not be used with the data available. For application of the Rates Approach it was decided that the assumption should be made that fluxes in the suction pipe were the same for the two loads but that any results generated should be treated with considerable caution.

The Reversed Screening Towers Approach to measuring the losses was not dependent on determination of the flux of sediment up the suction pipe. Using measurements of sediment levels within the hopper (and using an assumed porosity of 40%) it was calculated that 704 tonnes of material had been loaded into the hopper with the screening towers reversed. This value was checked against displacement data measured using the vessel's sensors and the two sets of measurements agreed remarkably well, the displacement data yielded a mass of 709 tonnes. Multiplying the rate at which screened (rejected) material was being generated by the duration of the cargo yielded an estimate of the quantity of rejected sediment that was within 25% of that derived using the Rates Approach.

5.3   Near-field Measurements Around the Dredger

Trialling of the MBSS in advance of the main three day study revealed that when working in close proximity to the dredger the orientation of the sonar head was critical to the quality of the data being returned. Directing the sonar towards the dredger often resulted in data of a poor quality (very high backscatter and little ability to identify features such as sediment plumes within the water column). This knowledge was used to inform the main survey around the dredger operating in the Eastern English Channel.

Sample data from the MBSS are presented in Figure 11. The system was able to identify sediment plumes through the full range of depths beneath the sensor head and to provide information on the extent and form of such plumes.

It was frequently the case that high backscatter intensity was identified in the upper water column (top 10 m) as presented in Figure 12. Such backscatter could at times be found well away from any sediment plumes and was thought to represent bubbles generated by wave activity. Close to the dredger such backscatter was often stronger, the likelihood being that bubbles generated by the discharges at the spillways and the screening towers were also contributing to the signal, along with sediment in the upper water column.

The results of the laboratory analysis of the water samples collected from 2 m depth during the near-field monitoring show that the sediment concentrations present were generally very low.

The minimum concentration measured was 1 mg/l and the maximum was 59 mg/l. The average concentration of all of the 90 near-surface samples collected was 14 mg/l.

When very high backscatter occurred in the upper water column (likely to have been due to the presence of bubbles or a combination of bubbles and sediment) at, or very close to, the sonar head, it appeared that the sonar's ability to detect targets beyond the backscatter was reduced. Noisy data with seemingly random high backscatter occurred (Figure 13).

Using the MBSS it was possible to detect sediment plumes in the water column up to ~700m from their generation point. In order to be able to identify the plumes at different distances from the dredger it was, however, necessary to periodically alter the instrument's settings.

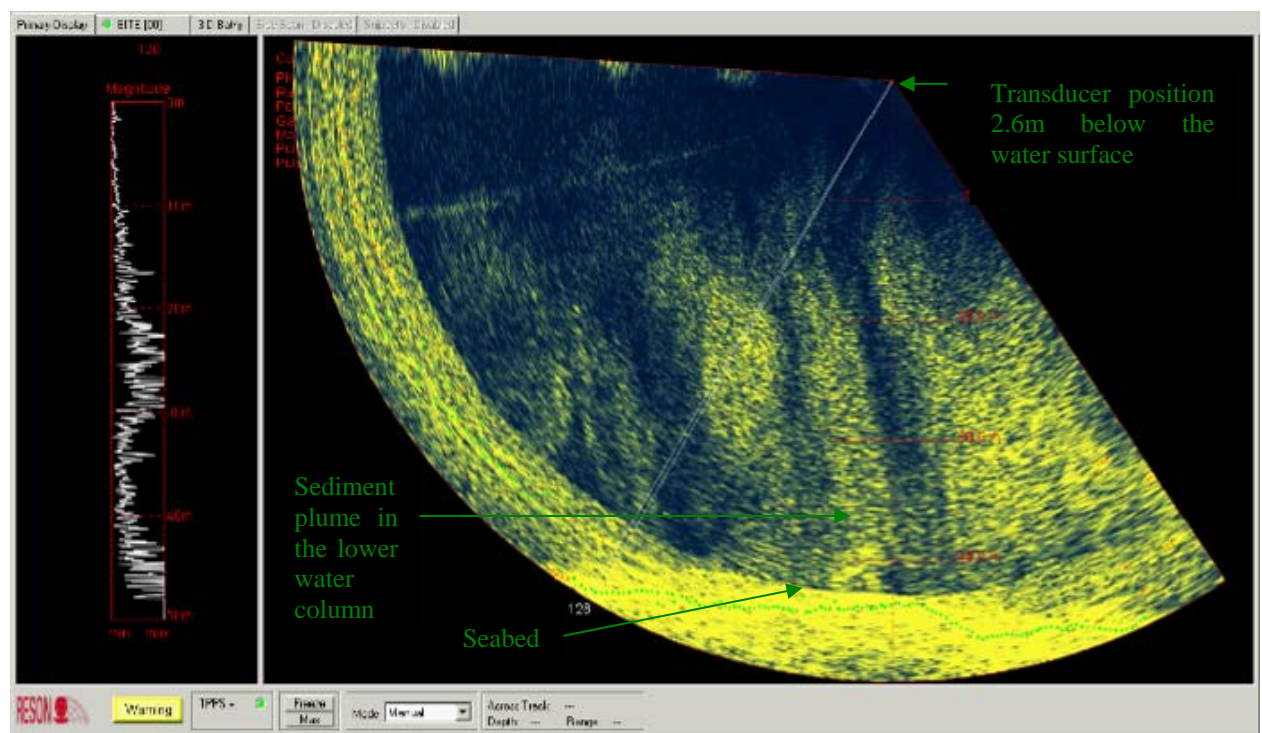Data return from the instrument was 100% with no downtime or data quality problems.

Figure 11   Sample MBSS data collected during the loading of the all-in load at 185m from the plume generation location
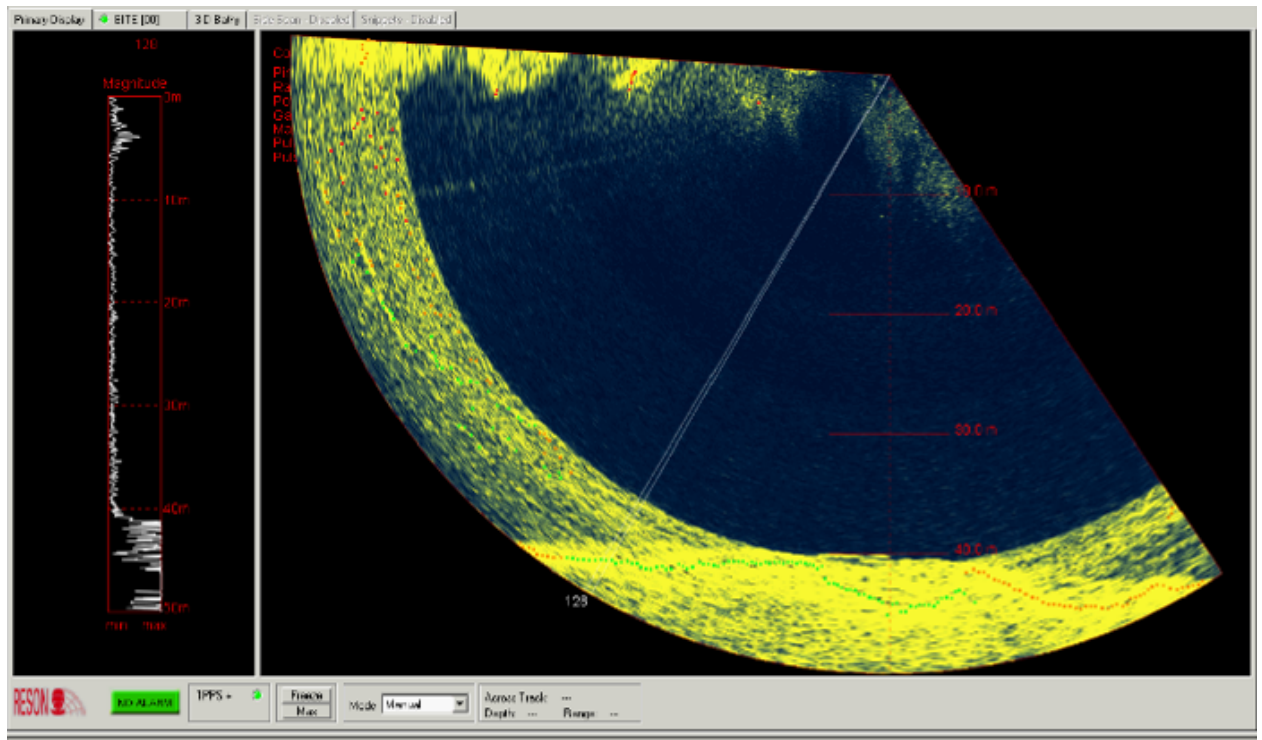
Figure 12 **Data recorded during the monitoring of the all-in load at a distance of 250m from the plume generation point showing high backscatter in the upper water column which is thought to be, in part, due to the presence of bubbles**
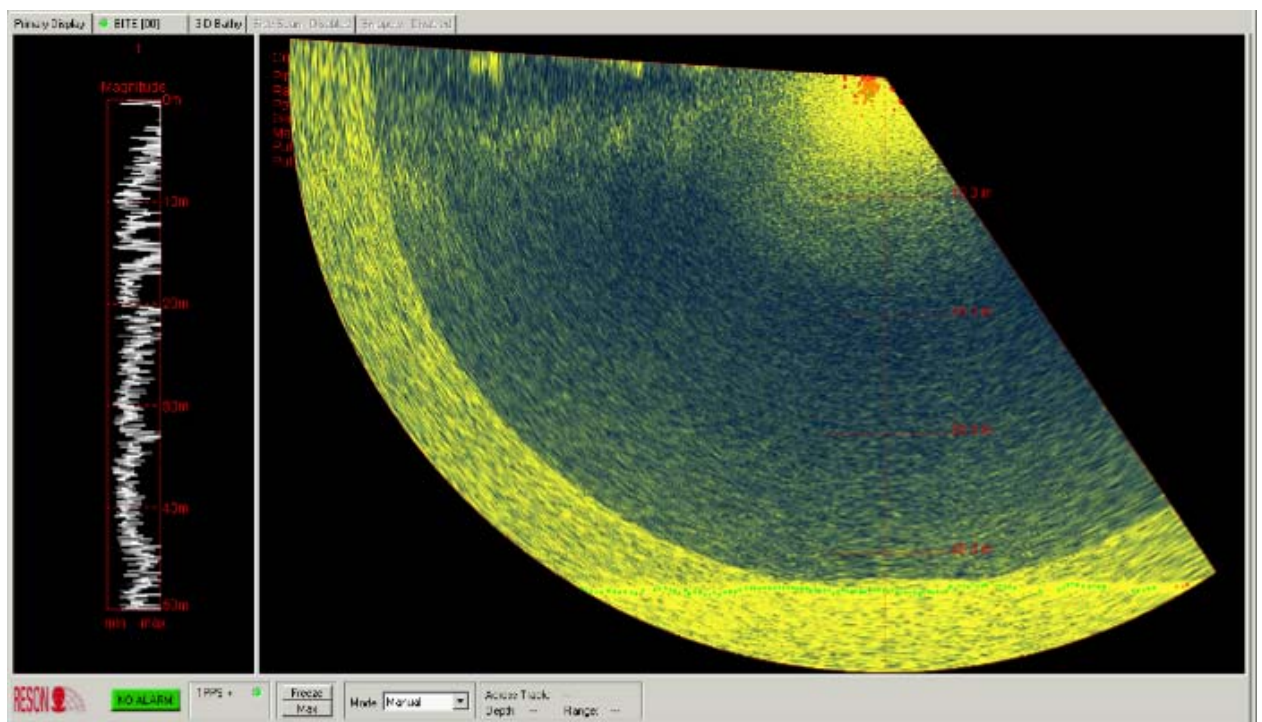

Figure 13 **MBSS data recorded during the monitoring of the screened load at a distance of 160m from the plume generation point, the effect on the data of the sonar head entering a region of very high backscatter near the surface (thought to be due to a combination of bubbles and sediment) is seen**

5.4   Far-field Measurements Around the Dredger

The ADCP used for the plume monitoring delivered a 100% data return during the 3 days survey. In total, 24 separate plumes were monitored, a total of 40 Sediview calibration data sets were collected and over 160 transects through the sediment plumes were run.

Calibration of the ADCP used for the measurements was successfully achieved via the Sediview technique (Land and Jones, 2001) using water samples from the Rapid Drop Profiler. Over the 3 days of the study the RDP was fired 120 times, however, on 16 occasions, the sampler misfired and on one occasion no sample was obtained. In total, therefore, 103 water samples were analysed for suspended solids concentrations and particle size distribution. A problem also arose with the RDP's turbidity sensor meaning that valid data were not collected for this parameter, however, this did not affect the ability of the instrument to deliver the necessary calibration data as the temperature and salinity sensors performed reliably.

During the study sediment plumes were monitored using the Sediview technique at distances between 80 m and 3,050 m from their generation points. A sample of the type of data generated by the measurements is presented in Figure 14. It should be noted that the approach is not capable of measuring data in the bottom 6% of the water column.
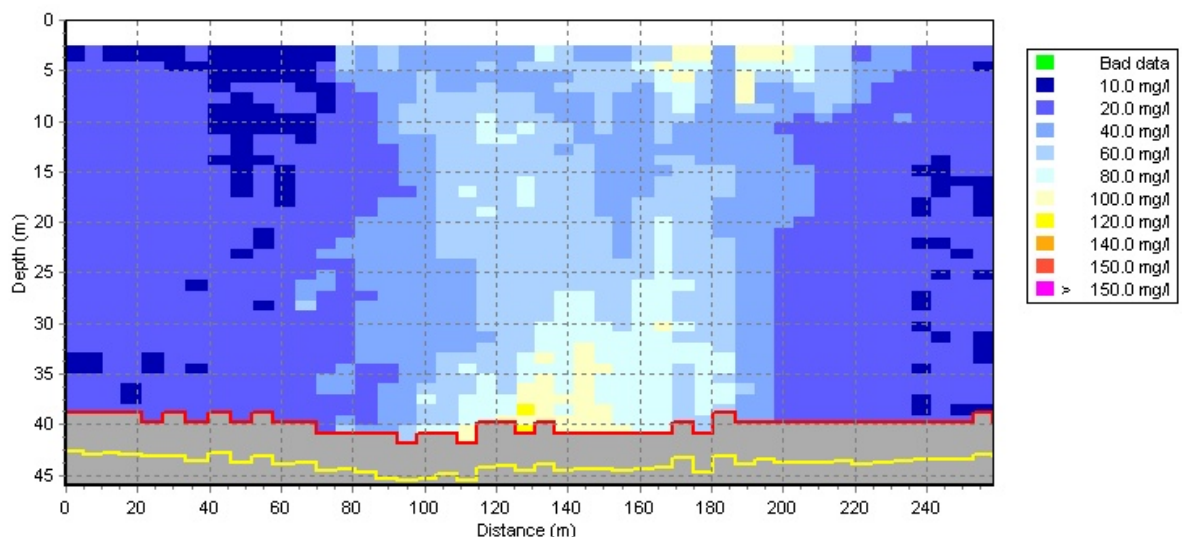

Figure 14   Sample ADCP transect data calibrated using the Sediview technique. The data presented were collected during the monitoring of the screened load at a distance of 380m from the plume generation point

5.5   Hydrodynamic Measurements

One hundred percent data return was achieved by both instruments. A sample of the data collected is presented in Figure 15.
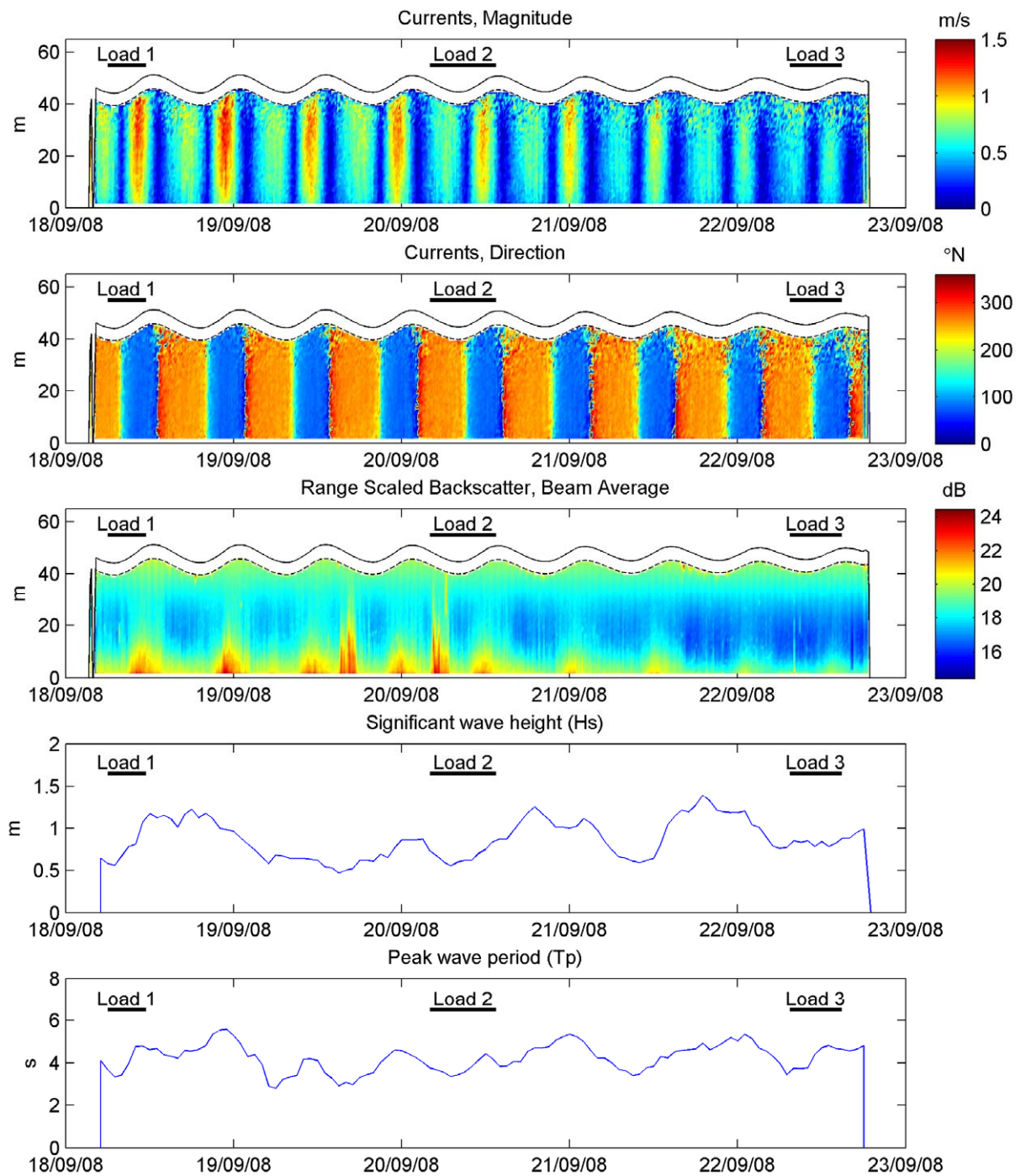
Figure 15 **Hydrodynamic measurements collected during the study at the western monitoring location (Instrument Frame 1)**

6   Study Findings

- Some monitoring approaches used in the past to measure plume source terms aboard aggregate dredgers are no longer permissible as a consequence of increased focus on health and safety. Within the present study alternative approaches to monitoring source terms aboard such vessels have been developed, tested and shown to be effective.

- Transmissometers can be employed to effectively measuring the concentration of silt in the overflow from dredger hoppers, even where large numbers of bubbles are present. Optical backscatter sensors are judged to be less well suited to this task; they appear to yield higher and more "noisy" readings when bubbles are present.

- Carousel type water samplers can be used effectively (following minor modification) both to measure sand concentrations in hopper overflow and to provide water samples for calibration of sensors measuring silt concentrations (e.g. transmissometers).

- Acoustic Doppler Velocimeters can be used alongside pressure sensors to successfully quantify the discharge through dredger spillways, even where large numbers of bubbles are present.

- A number of different approaches are available for the quantification of screening losses from aggregate dredgers, however, some of these are reliant on the accuracy of the vessel's installed sensors which may, in some instances, not be high. An approach with minimal reliance on the vessel's sensors is to reverse the screening towers through 180 degrees and (partially or fully) load the hopper with material that would normally be rejected overboard. This approach was found to be highly successful within the present study.

- Quantitative measurement of sediment plumes around dredgers can be undertaken very effectively using Acoustic Doppler Current Profilers (ADCPs) calibrated using the Sediview approach.

- Multibeam sonar systems can also be used to provide information on the nature of sediment plumes. Using multibeam, measurements can be collected close to the bed which is not presently the case with the Sediview system. However, disadvantages also exist in that the multibeam data cannot easily be calibrated to provide sediment concentration information and during the present study the multibeam was unable to detect such low concentrations as the ADCP was able to (although this may have been a function of the settings used).

- All of the instruments deployed were found to be highly reliable other than the Rapid Drop Profiler which failed to fire on occasions and suffered a turbidity sensor failure. Fortunately neither of these problems compromised the data collected during the study.

- It should be noted that the measurements were collected at a time when sea conditions were slight. In less favourable conditions we would anticipate that the carousel water samplers would require further protection from the elements.

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Acknowledgements

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