SECTION 4 - RESULTS OF OUR INVESTIGATIONS

Coastline Surveys Ltd have undertaken numerous and varied investigations into aspects of the dispersion of plumes associated with marine aggregate mining. This baseline project was divided into three main areas of interest, each with separate phases of investigation;

Phase One: ***determination of surface overspill and screening/rejection source terms and contributions to plume generation***

Phase Two: ***evaluation of plume survey, monitoring and representation techniques***

Phase Three: ***determination of benthic plume source terms generated by action of the draghead on the seabed***

Field campaigns undertaken during the project timespan have characterised overflow and, to a limited extent reject sediment/water mixtures, to determine the source terms of the surface plume. This has been done from a number of different vessels in different operational licence areas with different geological conditions. Table 4.0.1 summarises the field campaigns that have been undertaken during this project.

An extensive monitoring survey using the acoustic backscatter function of an Acoustic Doppler Current Profiler (ADCP^{TM}) was undertaken in August 1995 and a smaller exercise was undertaken in January 1997.

Also in January 1997, concurrent with the ADCP^{TM} profiling, underwater video cameras and pump sampling equipment was mounted on the dragarm and draghead of a TSHD during normal operations.

4.1 Phase One - Surface Plume Source Terms

The source term for modelling a surface plume is the quantity and quality of the suspended sediments. This may best be expressed by as a rate *i.e.* as unit weight of dry solids per unit time or per loading operation. Particle size distribution and shape (with very fine cohesive particles also density and mineralogy), are fundamental factors that will affect settlement rates and hence horizontal excursion. These must be investigated.

Prior to this study, few attempts appear to have been made to define these source terms using field data (notably some preliminary work undertaken by ARC Marine Ltd, SCS Ltd and UMD Ltd in 1992). Historically, analyses have largely been based on dredge manufacturer’s equipment design and operator’s performance data.

A fundamental objective of this study has been to collect reliable field measurements on source terms. The recent studies in Hong Kong have also considered the importance of field data and have collected detailed datasets (Land *et al*, 1994).

4.1.1 Overspill Volume

Other than manufacturers’ specifications on the pumping capacities of the dredge pumps, only the newer design of dredgers have electronic forms of loading gauges. On the largest vessel sampled, these had not been calibrated since manufacture of the ship. On the smaller vessels, loading gauges are not generally available.

Consequently it was necessary to determine the rate at which the pump worked, by verifying manufacturers’ specifications, in order to establish the quantities of material involved. It was then necessary to determine the proportion of the pumped material which was discharged overboard through rejection or through the spillways. Information generally available from manufacturers quotes pumping rates as water only, rather than water and sediment.

A number of options have been considered to determine the volume of material passing through the spillways, bearing in mind strict cost limitations.

Discussions with waste disposal and discharge consultants were initiated but abandoned largely due to the heavy financial implications of furthering their suggestions.

Date	Vessel	Loading Time	Screening Method	Licence Area	Samples Obtained
29.07.93	ARCO Adur	3 hours 10 mins.	14 mm screen (SAND)	202 Cross Sands	5 overspill
05.08.93	ARCO Adur	4 hours 20 mins.	10 mm screen (SCR BAD)	202 Cross Sands	8 overspill
06.08.93	ARCO Adur	3 hours 00 mins.	14 mm screen (SAND)	202 Cross Sands	7 overspill
08.08.93	ARCO Adur	4 hours 50 mins.	10 mm screen (SCR BAD)	212/5 Norfolk Bank	14 overspill
09.08.93	ARCO Adur	4 hours 40 mins.	10 mm screen (SCR BAD)	202/5 Cross Sands	12 overspill
11.08.93	ARCO Adur	5 hours 30 mins.	10 mm screen (SCR BAD)	242/8 Lowestoft Bank	15 overspill
12.08.93	ARCO Adur	4 hours 50 mins.	10 mm screen (SCR BAD)	212/5 Norfolk Bank	13 overspill
28.11.94	ARCO Severn	5 hours 10 mins.	10 mm screen (100mm SCALP)	124/1 Owers Bank	39 overspill
30.11.94	ARCO Severn	4 hours 10 mins.	10 mm screen (100mm SCALP)	124/1 Owers Bank	37 overspill
01.12.94	ARCO Severn	5 hours 40 mins.	10 mm screen (100mm SCALP)	124/1 Owers Bank	48 overspill
06.01.95	ARCO Severn	2 hours 10 mins.	no screens (ALL-IN)	124/1 Owers Bank	18 overspill
11.05.95	ARCO Severn	3 hours	no screens (ALL -IN)	124/1 Owers Bank	36 overspill
13.05.95	ARCO Severn	4 hours 10 mins.	10 mm screen (100mm SCALP)	124/1 Owers Bank	44 overspill
19.08.95	ARCO Severn	3 hours 30 mins.	no screens (ALL -IN)	124/8 Owers Bank	47 overspill
20.08.95	ARCO Severn	3 hours 40 mins.	10 mm screen (100mm SCALP)	124/8 Owers Bank	46 overspill
21.08.95	ARCO Severn	3 hours 30 mins.	10 mm screen (100mm SCALP)	124/8 Owers Bank	49 overspill
17.12.96	ARCO Severn	2 hours 30 mins.	no screens (ALL -IN)	124/1 Owers Bank	18 x draghead plume samples
14.01.97	ARCO Dee	3 hours	10mm screen (100mm SCALP)	124/1 Owers Bank	13 x draghead plume samples + video camera + ADCP
16.01.97	ARCO Dee	2 hours 45 minutes	10mm screen (100mm SCALP)	124/1 Owers Bank	video camera
17.01.97	ARCO Dee	2 hours 25 minutes	10mm screen (100mm SCALP)	366 Hastings Bank	video camera

Total samples collected: 469 (31 draghead plume, 408 overspill and 30 reject chute samples)

Total days at sea: 29

Table 4.0.1 *Summary of field work campaigns undertaken during this project*

Determination of the overspill volume has been assessed by a variety of techniques:

- seabed disturbances **-** analysis of seabed draghead disturbances by using detailed sidescan sonar mapping and processing to calculate sediment volume disturbed during each load (Davies & Hitchcock, 1992)

- time series analysis **-** comparison of manufacturers' specifications for pumping rates, loading times and range of variations

- analysis of the solids' concentration of the overspill and rejected suspensates by extensive sampling and laboratory testing

- *in situ* measurements using conventional vane and modern electromagnetic current meters combined with high quality video records and PC image processing to determine flow rates

- by combining field observations and design specifications of the loading performance of typical TSHD, the total dry solids returned through overspill can be estimated

Comprehensive analysis of the seabed disturbances caused by aggregate dredging activities had been undertaken immediately prior to this project and is reported in Marine Technology (MTD) Report No. GR/G 20059, Davies and Hitchcock, 1992. Observations during the MTD project suggested considerably more seabed material was disturbed than was loaded aboard the dredger.

Detailed measurements of high resolution sidescan sonar images of the draghead furrows were manipulated and processed using novel modelling techniques. Identification of different shape seabed furrows was largely attributable to particular types of draghead operated by different vessels. Plate 4.1.1a shows the condition of the seabed after passage of the draghead, and unaltered deposits alongside. The development of small sand ripples, orientated perpendicular to the direction of passage of the draghead is clear and has been observed from sidescan sonar imagery (Davies & Hitchcock, 1992).

Plate 4.1.1a *Underwater image taken 2 weeks after trial dredging off Norfolk showing effects of draghead on removal of coarse sediment and development of small sand ripples within the dredge furrow. Area of photograph about 0.7m2 (from Crown Estate, 1994)*

'W' and 'M' shape furrows, largely caused by 'A' class and 'T' class dredge vessels mainly using 'California' Type dragheads (but not always), suggested most disturbance at the seabed. Figure 4.1.1a illustrates the principle types of furrow that were identified and their main features. Table 4.1.1a summarises the proportions of draghead furrows measured from sidescan sonar imagery.

Plate 4.1.1b *TSHD ARCO Thames almost fully loaded, English Channel, August 1995*

	'T' Type furrow	'M' Type furrow	'W' Type furrow
Profile Depth (m)	0.547	0.522	0.342
Profile Width (m)	2.822	2.509	3.687
Levée Height (m)	n/a	0.224	0.220
Overall Width (m)	2.822	3.884	4.824
Net Cut Depth (m)	0.547	0.401	0.187
Outer Slope Angle (^{o})	n/a	10.98	18.07
Profile Cross Section (m^2)	0.665	0.514	0.391
Levée Cross Section (m^2)	n/a	0.113	0.083

Table 4.1.1a *Summary of principle draghead furrow dimensions obtained using sidescan sonar imagery and modelling techniques (after Davies & Hitchcock, 1992)*

Davies & Hitchcock (1992) provides a first approximation to the amount of material that is displaced, mostly removed from the seabed, partially retained as the cargo load and otherwise returned overboard. Using a series of averages, for recorded field data, a 'T' class dredge vessel (load of 3400 tonnes) (Plate 4.1.1b) was observed to displace 16,194 tonnes of material, creating levées totalling 1,919 tonnes, and consequently generating overboard returns of some 10,875 tonnes of sediment. The data suggest that 3-6 times the cargo load is disturbed on the seabed, with 0.5-2 times the cargo left on the seabed as levées or other internal microstructures. The overboard returns suggested by this data may therefore be of the order 2 - 4 times the cargo load.

Detailed time series analysis of the loading rates for differing types of cargo was then undertaken to determine a second approximation of the volume of material returned overboard (Table 4.1.1b).

	ARCO Severn			ARCO Adur		
Area	All-in	Stone	Sand	All-in	Stone	Sand
106	---	---	---	---	4:18 (11) *3:12-7:30*	4:01 (5) *2:48-6:42*
112	4:36 (1)	6:06 (2) *4:36-7:36*	9:12 (2) *7:06-11:18*	---	---	---
124/1	3:35 (30) *2:06-4:24*	4:03 (197) *2:18-6:42*	---	---	---	---
124/2	3:36 (1)	4:41 (8) *3:12-5:30*	---	---	---	---
127	3:26 (6) *2:42-4:15*	4:11 (43) *2:18-6:18*	---	---	5:00 (1)	---
202	---	---	---	1:39(2) *1:30-1:48*	6:22 (82) *4:00-9:36*	---
212	---	---	---	---	6:11 (109) *4:18-9:12*	2:13 (9) *1:48-3:00*
221	---	4:27 (2) *3:54-5:00*	4:02 (3) *3:36-4:18*	---	6:22 (30) *4:48-8:24*	---
242	3:17 (4) *2:42-4:45*	4:07 (49) *2:18-7:18*	---	---	6:43 (26) *4:24-9:00*	---
328	---	---	---	---	6:04 (63) *2:30-10:54*	---
361	---	---	---	---	6:58 (31) *4:42-10:36*	---
366	2:58 (36) *2:18-3:48*	---	---	3:06 (1)	---	---
888	2:46 (10) *2:15-3:15*	---	---	---	---	---
All areas	3:14 (88) *2:06-4:45*	4:07 (301) *2:18-7:36*	6:01 (5) *3:36-11:18*	2:08 (3) *1:30-3:06*	6:13 (353) *2:30-10:54*	2:52 (14) *1:48-6:42*

Table 4.1.1b *Analysis of loading times for 'A' Class and 'S' Class TSHD. Variations due to loading area geology and cargo type, plus other factors such as weather and cargo pump condition*

The third approximation for the quantity of material returned overboard involves analysis of the specific gravity of the overboard returns through the reject chute and the spillways. To determine the quantity of material pumped it is assumed that the density of material pumped will remain constant for different types of cargo *e.g.* all-in or screened. However it is likely in practice that this will vary within certain operational limits, according to the geology of different licences. By experience, dredge Masters will operate the vessel at the optimum pump mixture density. Alterations may be made by changing speed over the ground, angle of the draghead on the seabed, or with some dragheads, opening water inlet valves.

Vessel Type	Cargo Type	Loading Time	Pumping Rate	Volume Pumped
'A' Class	no screening (all in)	1 hour 55 minutes	$7750m^3$/hr	$14,854m^3$
'A' Class	screening for sand (stone out)	3 hours 5 minutes	$7750m^3$/hr	$23,895m^3$
'A' Class	screening for stone (sand out)	4 hours 50 minutes	$7750m^3$/hr	$37,460m^3$
'S' Class	no screening (all-in)	3 hours 20 minutes	$4500m^3$/hr	$15,000m^3$
'S' Class	screening for stone (sand out)	4 hours 23 minutes	$4500m^3$/hr	$19,725m^3$

Table 4.1.1c *Time series analysis of average loading performance for selected vessel types under normal conditions as observed during field work*

Analyses of some 408 samples have enabled average suspended solids concentrations and particle size distributions (not all of the dataset) to be determined. These have been further analysed using a simplified iterative loading model to determine the correct input quantities to return the observed outputs from the dredger.

The average density of the pumped mixture for an 'A' class type vessel has been determined as 1.2128 kg/m^3 and for 'S' class as 1.1974 kg/m^3 (B. Jackson *pers. comm.*). Using these values, and from Table 4.1.1c, an 'A' class vessel loading a stone cargo (sand out), pumping approximately $37,460m^3$ of mixture, will therefore pump 12,158 tonnes of dry solids mixed with some 33,356 tonnes of seawater. Retaining 4,185 tonnes of sediment as cargo, it therefore follows that some 7,973 tonnes of sediments will be returned overboard during the load.

From Table 4.1.1c a range of values for the volume of material pumped can be determined according to vessel type and load. Loading times for an 'A' class type vessel will vary between less than 2 hours for 'all-in', averaging 4 to 6 hours for screening. Exceptionally, cargoes may take 9 to 10 hours to load though this is commonly due to bad weather or worn dredge pump impellor. The smaller 'S' class vessels take a shorter length of time to load under normal conditions, loading less material at a slower rate.

Modern dredgers such as the City of Cardiff have pumps capable of loading mixture at $1.5m^3$/s. Vessels such as the City of London and City of Westminster (similar to 'A' class) will load mixture at approximately $2m^3$/s (A. Bellamy, *pers. comm.*)

Ignoring the quantity of sediment disturbed at the seabed but not actually raised from the seabed, a 'loading efficiency' may be considered as the ratio of load retained to the quantity of sediment pumped and thus averages 37% for a screened stone cargo (1:3). Similarly, loading efficiencies may be 58% for screened sand cargo and as high as 93% for 'all-in' cargoes. Table 4.1.1d presents some comparisons for different vessels.

Cargo Type	**'A' Class**
no screening (all in)	93%
screening for sand (stone out)	58%
screening for stone (sand out)	34%

Table 4.1.1d *Loading efficiencies for 'A' Class vessels. Loading efficiency is defined as the ratio of load retained to the total quantity of sediment pumped*

Finally, a fourth set of data was collected to clarify the distribution of overboard returns between overspill and rejection by screening. Detailed measurements of the flow velocities encountered within the overspill weirs were made (Plate 4.1.1c). Using a combination of traditional vane (Valeport) current and modern electromagnetic (Marsh McBirney) current meters combined with high resolution computer processed video imagery, the rate of material passing over the spillways was determined. Measurements were made (some 15000 at 2 second intervals) for the duration of the load for different cargoes. The differences between overspill rates during loading all-in and screened cargoes can consequently be attributed to the proportion of pumped mixture passing overboard through the reject chute (Table 4.1.1e).

Date	Cargo Type	Ship	mean overspill velocity (m/s)	mean depth (m)	mean rate (m^3/s)
06.01.95	all-in	‘S’ Class	2.505	0.079	0.336
11.05.97	all-in	‘S’ Class	2.345	0.074	0.310
13.05.97	stone (sand out)	‘S’ Class	1.54	0.051	0.178

Table 4.1.1e *Summary of the flow observations made in the starboard side aft spillway (per overspill channel). The difference between screening and non-screening assists derivation of the ratio between overspill and rejection by screening*

Plate 4.1.1c *Electromagnetic current meter and measuring gauges set within the spillway of the ARCO Severn. Simultaneous video imaging and analysis has enabled calculation of volume, determination of overflow rate and therefore ratio of overspill to rejection components*

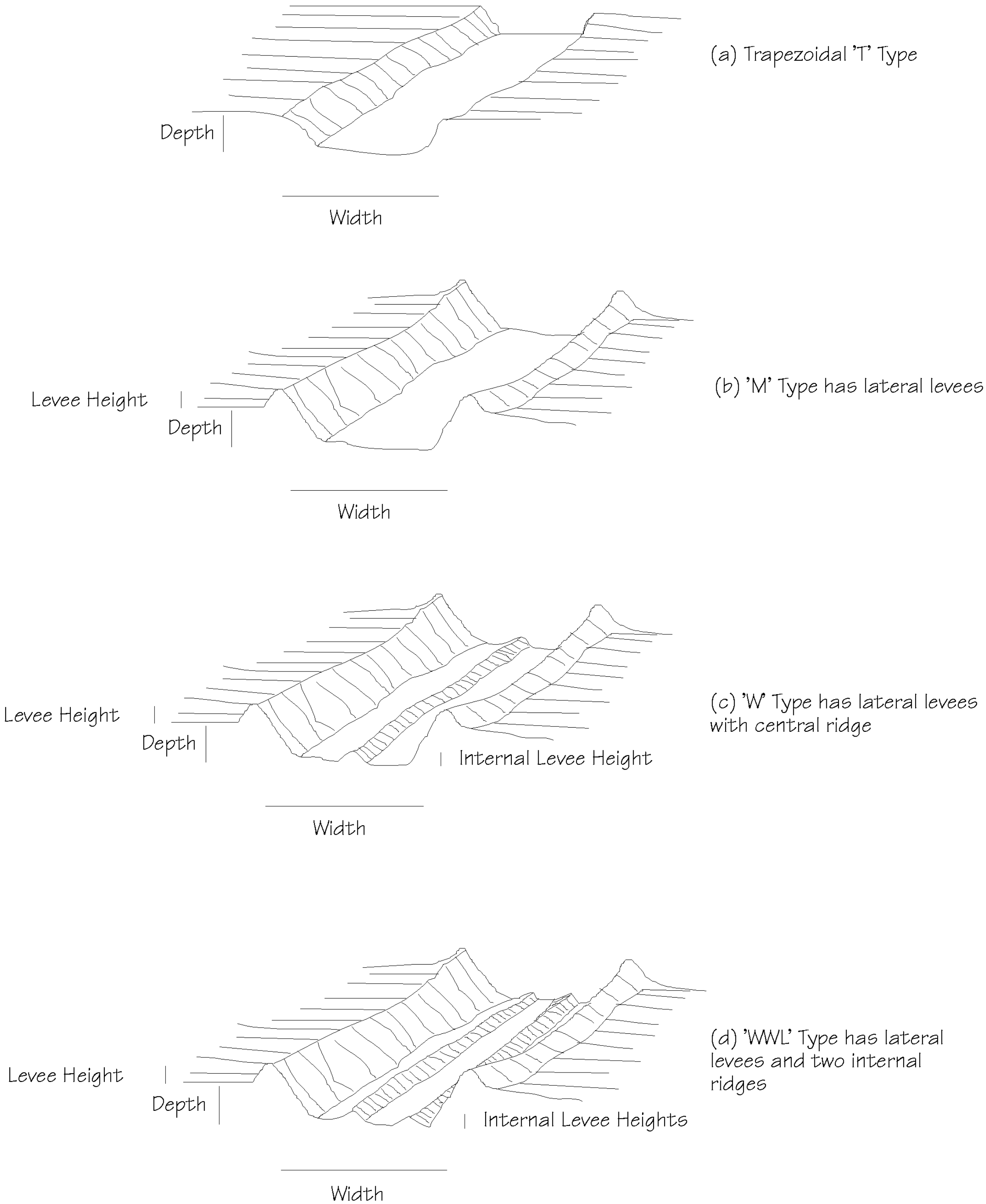

Figure 4.1.1 *Primary seabed furrow characteristics formed by dragheads commonly used for aggregate dredging in the United Kingdom*

4.1.2 Volume Returned Overboard Due To Screening

Screening of the pumped mixture is necessary to improve the stone content of most cargoes to that which is required by the market. A dredged cargo containing too much sediment of the wrong fraction, be it too little or too large, will be rejected by the Customer.

With some notable exceptions, screening during loading is permitted on all Licence areas in the UK. Screening may become necessary due to Licences working through various grades of deposit, licences with marginal quantities of the sediment fraction required, wear of the dredge pump or special Customer requirements.

Whilst meeting Customer requirements through using screening at sea, the Dredging Company may not favour extensive use of the practice largely due to (a) increased wear and tear on the dredging plant and (b) perceived impacts of a larger plume generated over a longer period.

A proportion of a given plume may be attributed to the process of screening. Not only is solids material returned overboard at a higher concentration, but this is done for a longer period.

Using a combination of time series analysis, measurements of the overspill volume and concentrations during a number of loads and from manufacturers specifications, estimates have been made of the contribution of screening to the overboard returns. Table 4.1.2a summarises these for the ‘A’ class type of vessel.

Overboard returns via	% solids pumped	% water pumped
reject chute	88%	35%
spillways	12%	65%

Table 4.1.2 *Proportions of material returned overboard by an ‘A’ Class vessel due to screening and overspill when loading a stone cargo (sand out) as a percentage of the total amount returned overboard during normal aggregate dredging based on field measurements and processing*

4.1.3 Granulometric Distributions Of The Overspill Sediments

Sampling campaigns have been conducted in a number of areas aboard different sizes of dredge vessels. Over four hundred samples have been obtained from the hopper overflow and thirty samples from the screening reject flows using equipment and techniques developed for the study. There has been no conscious control over the geographical location of the sampling campaigns, making best available use of vessels wherever they may become available. Some 30-40 samples are obtained from each loading effort, generally from alternate spillways on the starboard side. For operational safety, stations on the port side have not been sampled on these particular vessels since that is the side of the dredge pipe and there is a hazard of injury from the suspension wires.

Sampling was attempted using Van Doorn remotely tripped sample bottles but these were damaged during the deployment, largely due to the significant volumes of material concerned. Secondly, sampling tubes were designed and fitted to the spillways in order to direct overspill back towards the deck for placing in a container. Whilst these were successful during ‘all-in’ loading, when there is no screening, overflow during screened loading is reduced to such an extent that the sampling tubes were no longer suitable.

The simplest, and what has proven the most effective, is to collect overspill using a bucket suspended by a rope. Some degree of care is required to ensure the bucket is not ripped out of the surveyors’ hands, and also to ensure a representative sample is obtained. To avoid retaining an unrealistic proportion of coarse sediment due to splashing out of the finer sediment laden waters, it was found that a large 20 litre bucket best suited sample collection used in a number of small attempts, say 1-2 litres each time.

During the collection of samples it was noted that due to vessel trim and motion, regions of the spillway will be sediment rich and others lean. The sediment rich areas may again be subdivided into coarser and finer sediment zones. Using the number of small samples reduced potential inaccuracies here.

Plate 4.1.3 *Sampling from the overspill*

Table 4.1.3a below presents the source terms of overspill determined for approximately 360 samples obtained from two different dredge vessels working a total of five different Licence Areas. As would be expected, it is evident that the overspill solid/water ratio varies considerably according to the mode of dredging *i.e.* whether screening is taking place or not, for example, during loading of screened stone cargoes aboard an 'S' Class vessel solids content of the overspill may vary up to threefold. For the studies undertaken here, concentrations of overflow sediments vary between 5.5kg/l and 35.2 kg/l, with a mean of 19.95kg/l, depending on the dredger.

Vessel Type	Cargo Type	Licence Area	Solid/Water Ratio (kg/1000l)	S.G. Of Mixture (S_m)	Solids By Volume (C_v) (%)	Solids By Weight (C_w) (%)
'A' Class	sand	202/5 Cross Sands	35.2	1.046	2.809	7.115
'A' Class	stone	202/5 Cross Sands	22.2}	1.038}	2.332}	5.950}
		242/8 Lowestoft	18.3} 29.3	1.036} 1.043	2.189} 2.593	5.599} 6.588
		212/5 Norfolk	30.3}	1.043}	2.628}	6.676}
'S' Class	stone	124/1 Owers Bank	16.0}	1.035}	2.105}	5.391}
			14.3	1.034	2.043	5.237
		124/8 Owers Bank	5.5}	1.028}	1.718}	4.428}
'S' Class	all-in	124/1 Owers Bank	25.4}	1.040}	2.448}	6.236}
			18.6	1.036	2.202	5.630
		124/8 Owers Bank	6.7}	1.029}	1.765}	4.545}

(Specific Gravity (S_m) of sand/gravel = 2.65)
(Specific Gravity (S_w) of seawater = 1.025)

Table 4.1.3a *Source terms of overspill from aggregate dredgers during normal commercial operations*

Towards the end of loading, especially on the larger vessels, gravel sized material is often washed out of the hopper. Consideration of the results must bear this in mind, as it may suddenly alter the appearance of net losses in the final stages of loading.

A number of samples were duplicated at 10 litre and 20 litre sizes to assess any sensitivity of the results to sample volume and sampling techniques. None was found.

Granulometric analysis of the samples by accredited soils laboratories has provided information on the particle size distribution of the overboard returns. This is a key requirement in providing a basis for the determination of the impact of a plume. Evaluation of each fraction of sediment is necessary to assess transport rates and settlement patterns. Table 4.1.3b summarises the observed distribution of particle sizes of material sampled in the overspill.

Importantly, independent results of a similar order have been recorded recently elsewhere, which supports the methodology and interpretation used in the this project. Gajewski & Uscinowicz (1993) report overspill source term values of 1.5kg/l to 11.25kg/l with a mean of 7.87 kg/l, using a smaller dredger. Particle size distribution data was fine sand (0.25-0.125mm) mean 56.3%, very fine sand (0.125-0.063mm) mean 10.1% and less than 1% fines (<0.063mm) (*see* Land *et al*, 1994; Whiteside *et al*, 1995; HR Wallingford *et al*, 1996;

see also Willoughby & Foster, 1983; Pagliai *et al*, 1985; Bonetto, 1995*).*

Particle Size (mm)	Combined Cargoes 'A' Class	Combined Cargoes 'S' Class	Sand Cargo Only 'A' Class	Sand Cargo Only 'S' Class	Stone Cargoes 'A' Class	Stone Cargoes 'S' Class	All-In Cargo Only 'A' Class	All-In Cargo Only 'S' Class
<0.063	39.3%	22.2%	18.4%	n/a	42.7%	22.7%	n/a	22.0%
0.063-0.125	14.3%	15.3%	5.2%	n/a	15.8%	16.9%	n/a	12.7%
0.125-0.250	8.2%	34.6%	24.5%	n/a	5.4%	35.6%	n/a	32.8%
0.250-0.500	14.5%	24.5%	36.8%	n/a	10.8%	22.2%	n/a	28.3%
0.5-1.0	8.1%	2.4%	9.7%	n/a	7.8%	1.9%	n/a	3.2%
1.0-2.0	2.8%	0.5%	2.8%	n/a	2.8%	0.4%	n/a	0.5%
>2.0	12.8%	0.5%	2.6%	n/a	14.7%	0.3%	n/a	0.5%

Table 4.1.3b *Proportions of materials in overspill discharge measured from two different dredge vessels (all results, sand, stone & 'all-in' cargoes)*

4.1.4 Granulometric Distributions Of The Reject Chute Sediments
Collecting information on the reject chute has been limited due to the physical nature of the discharge. The volume and velocities encountered are considerable which requires any field equipment to be extremely rugged. A limited number of samples have, however, been obtained from an 'A' Class vessel which have then been analysed following similar procedures to the overspill samples (Plate 4.1.4). Full particle size analysis has been carried out by accredited laboratories.

Plate 4.1.4 *The practicalities of sampling the screened-off material from the reject chute*

Table 4.1.4 summarises the distribution of the particle sizes amongst the rejected materials for the 'A' Class vessel type only.

It must be remembered that these are provisional datasets only based on a limited number of samples. There is considerable difference between the distributions for the two types of cargo, as would be expected. However, it is somewhat surprising how much of the required cargo is actually lost through the reject chute. When loading a stone cargo, for example, 18.5% of the rejected material, amounting to some 1298 tonnes (31% of the cargo load), is of a size greater than 2mm, much of which may be desired cargo.

It is proposed that further investigation of the rejected material is carried out. This may assist in improvements to loading efficiency.

Particle Size	Sand Cargo Only		Stone Cargoes	
(mm)	'A' Class	'S' Class	'A' Class	'S' Class
<0.063	0.1%	n/a	1.0%	n/a
0.063-0.125	0.2%	n/a	0.9%	n/a
0.125-0.250	2.1%	n/a	8.9%	n/a
0.250-0.500	10.1%	n/a	31.4%	n/a
0.5-1.0	9.9%	n/a	27.3%	n/a
1.0-2.0	4.1%	n/a	12.0%	n/a
>2.0	73.5%	n/a	18.5%	n/a

Table 4.1.4 *Proportions of materials in reject discharge measured from the 'A' Class dredge vessels (screening for sand and stone cargoes)*

4.1.5 Dredging Scenario: Screening For Stone Cargo Using Large Trailing Suction Hopper Dredger Of 'A' Class Type

Continuing the previous example in Section 4.1.1 for the loading of an 'A' class dredger, using Tables 4.1.1b through to Table 4.1.4 (8 Tables) we can calculate the following:

(1) 12,158 tonnes of dry solids are loaded with 4,185 tonnes of dry solids retained as cargo. 7,973 tonnes dry solids pass overboard split as 957 tonnes due to overspill and 7016 tonnes due to rejection by screening.

For this particular type of screened stone cargo, the data having been obtained from a Southern North Sea location, the ratio of retained to rejected material is approximately 1:2. This would indicate an *in situ* particle size distribution of 34% stone to 66% sand (including fines) sized material on the seabed. We must assume there is no bias of sediment sizes pumped caused by preferential extraction and/or seabed screening occurring within the suction and pumping processes.

The *in situ* distribution calculated correlates well with the prospecting data obtained through grab sampling and vibrocoring at the site which indicate an average of 30% gravel, 69% sand and 1% silt (A.R. Hermiston, *pers. comm.*)

(*2) coarse material (> 2mm): some 140 tonnes (14.7% of 957 tonnes) material greater than 2.0mm will be lost overboard through the spillways, mostly towards the end of loading as the cargo approaches the top of the hopper. 1,298 tonnes of sediment greater than 2mm will pass over the reject chute. This equates to a overboard returns rate of material entering the water column of 8.0kg/s and 74.6kg/s respectively*.

Assuming an average ground speed of 1 knot this equates to a flux of material entering the water column at 4.1kg/s/m and 38.4kg/s/m respectively. Much of the material is likely to be in the size range 2.0mm - 10.0mm due to the reject screen size used. Material of this size and coarser sizes can be expected to fall almost instantaneously to the seabed with very little horizontal displacement.

Video records of draghead activity during normal loading operations (A.R. Hermiston, *pers. comm. and* Davies & Hitchcock, 1992) clearly indicate such material reaching the seabed directly under the vessel.

Measurements (scaled from photographs) of the average size of the individual plumes entering the sea surface (which vary according to vessel draft) give an estimate of the entry surface area into the water column as 5.88m^2 for the overspill plumes and 1.5m^2 for the reject chute.

The flux of coarse material entering the water column can therefore be estimated as 0.18kg/m^2 of sea surface for overspill and 6.6kg/m^2 for the reject chute at a speed of 2 knots (0.36/kg/m^2 and 13.2kg/m^2 respectively for 1 knot).

(3) sand fractions (0.063mm to 2.0mm) will amount to 407 tonnes (23.4kg/s) and 5,647 tonnes (325kg/s) from the overspill and rejection processes respectively. At a ground speed of 2

knots this would equate to 1.0kg/m^2 for overspill and 55.8kg/m^2 for rejection of sand.

(4) silt and clay fractions (<0.063mm): up to 408 tonnes of fines may be lost through overspill and 70 tonnes via the rejection process (23.5kg/s and 4.0kg/s respectively). Again, at a speed over the ground of 2 knots, this equates to a flux entering the top of the water column at a rate of 1.0kg/m^2 due to overspill and 0.69kg/m^2 due to screening.

Sediments of this size may be expected to disperse more slowly than the coarser fractions, typically with a settling velocity in the range 0.1-1.0mm/s. In its simplest form, the settling velocity can be determined by Stoke's Law assuming that the flows within the water column do not have any vertical components. Residence time in suspension and current flow and direction will therefore determine the excursion pattern before settlement. Resuspension of the recently-settled material before consolidation must further be considered.

The relationship with settling velocities and the importance of correct determination of settling velocities as applicable to the actual sediments disturbed by the dredging operation, rather than settling rates of idealised, single particles is crucial to correct study of plumes and is discussed further elsewhere in this report.

4.1.6 Variance Of Data

Throughout the investigation, it has become clear that there is significant variation in operating performances between ships, between licences, between cargoes for different Customers and even between different crews of the same vessel. The production of definitive tables stating the various throughputs of the system is unlikely to be realised. We have, in this report, attempted to produce mid-range figures for much of the data.

It is accepted that there will be significant differences between these data and any further data that may be obtained, concerned with specific ships and specific case studies. Nevertheless, the field data are considered to be accurate to some 10-15% on the day of measurement, and the consequent manipulation of data is expected to realise answers that conform to this accuracy.

It is expected that in reality, some parameters for various different types of ships and Licence conditions may vary by 50% or more. The critical importance of obtaining valid field data to investigate dredging equipment or conditions not encountered during this study cannot be overstated.

The following Table, 4.1.6, demonstrates the variability that may be encountered between different cargoes on the same licence area, albeit with some slight local geological differences (hence the use of different 'runs' or 'zones').

Particle Size	All-In Cargoes Only, S Class		Stone Cargo Only	
	Area 124/1/1	Area 124/1/8	Area 124/1/1	Area 124/1/8
<0.063mm	5.5%	48.1%	6.2%	68.3%
0.063-0.125mm	14.1%	10.6%	18.9%	11.1%
0.125-0.250mm	41.5%	19.0%	44.1%	11.6%
0.250-0.500mm	33.8%	19.7%	27.2%	7.7%
0.5-1.0mm	4.1%	1.8%	2.3%	0.7%
1.0-2.0mm	0.6%	0.5%	0.4%	0.5%
>2.0mm	0.4%	0.3%	0.9%	0.1%

Table 4.1.6 *Proportions of materials in overspill discharge measured from one dredge vessel in two different portions of the same Licence Area ('all-in' and stone cargoes only)*

It is implied by the data above that the silt content of Area 124/1/8 is some ten fold greater than that of Area 124/1/1. In truth, analysis of the detailed prospecting and reserve evaluation data reveals

that the exploitable geology of Area 1241/1/1 is in fact a broad paleo-terrace reserve consisting largely of sand and gravel. Area 124/1/8 however is a localised river channel deposit consisting of sands and gravels but over, and surrounded by, clays and silty clays respectively.
It therefore seems likely that when loading on Area 124/1/8, any slight positional deviation away from the localised gravel/sand deposit will result in dredging appreciable amounts of silt/clay deposits which are then immediately washed back overboard (by raising the draghead and pumping water only across the top of the cargo). Similar positional deviations within Area 124/1/1 would not result in similar contamination of the cargo by such silty/clay sediments.

The accuracy of both the known dredger position and real-time reference to geological information is therefore important. It follows that geological survey information must be at a higher density in areas of patchy resource, than in broader sheet-formation reserves.

4.1.7 Summary Of Source Term Observations

The data on plume source terms which have been collected during this project conform well with other sources of information. We have substantiated earlier projections of overboard losses of sediments based on analysis of seabed disturbances (Davies & Hitchcock, 1992). The quantities of material displaced on the seabed and subsequently returned overboard *via* the reject chute and spillways conform with very little discrepancy. Estimations (by multiple techniques) of the volume of material returned overboard and the proportional split of such volumes have been made and these agree (within the range of error) for each determinable factor. Field investigations of the content of the overspill and reject mixtures have conformed with expectations, predicted from seabed sediment reconnaissance and cargo analysis. 409 samples have been obtained from the overspill. Information with regard to the content of the rejected mixture is not statistically robust (only 30 samples) and further field information is required. This needs to be obtained from different types of cargo (sand and stone) and from different classes of dredger. Data from an ‘all-in’ cargo are useful for comparison.

In order to evaluate the impact of marine aggregate dredging, three distinct scenarios exist; loading all-in; screening for sand; and screening for stone. Further combinations of scenarios may be considered related to the type of dredging; anchored or trailing; size of dredger; type of screening (central ‘boiling box’ and ramp or screening towers); type of overspill (central column or conventional spillways); and geology. It is therefore important to consider each application of a dredging ‘activity’ in relation to its specific format.

In broad terms, we can summarise the source term information and the primary dredging scenarios as presented in Table 4.1.7 below.

Cargo Type	‘A’ Class	‘S’ Class	‘T’ Class*
no screening (all in)	0.2 - 1	0.5 - 1.5	0.5 - 1
screening for sand (stone out)	2 - 3	2 - 4	2 - 3
screening for stone (sand out)	3 - 5	3 - 4	3 - 4

* estimated from Davies & Hitchcock (1992)

Table 4.1.7 *Proposed dimensionless values for the quantity of material returned overboard (rejected and overspill) as a multiple of the cargo load during normal aggregate dredging based on extensive field measurements and processing. A further 12% will be disturbed at the seabed and left as microstructures associated with the passage of the draghead. The lower disturbance values may be expected at the start of a dredging licence life period - with time and the resource becomes thinner and the potential for ‘oversanding’ occurs, which may increase the loading times.*

It follows that using Table 4.1.7 and a known ship cargo capacity *e.g.* a ‘T’ Class (3400 tonnes), we can estimate that for a screened sand cargo scenario some 6800 tonnes of sediment may be returned overboard. A further 1224 tonnes will be pushed aside on the seabed and left as microstructures associated with the passage of the draghead (*for example*, levées, internal ridges *etc.*) That is to say the gross sediment displacement by the draghead will be 11424 tonnes. Using the same ship to load an all-in cargo, the gross disturbance will be 5712 tonnes (3400 tonnes cargo; 1700 tonnes overboard; and 612 tonnes displaced but not removed from the seabed). It must be remembered that these will vary, perhaps up to a factor of 2, according to a combination of dredge vessel, dredge vessel pump wear, weather conditions and Master experience.

When loading a stone cargo (sand out), the proportional split of the overboard returns between the reject chute and overspill is approximately 7:1 (solids) and 1:2 (water) respectively. Further, the Tables indicate the percentages of overspill as sediment size fractions. This fundamental information allows not only refining of the source term inputs to numerical models, but also an assessment of the efficacy of loading and screening processes. Table 4.1.3b indicates that, for example, when loading sand cargoes on an 'A' Class dredger, 61.3% of the overspill (*approx*. 5130 tonnes) is of size 0.125-0.5mm).

Importantly for numerical modelling, the density of the overspill jet may often, but not always, be greater for larger vessels than smaller vessels. From Table 4.1.3a the overspill mixture during loading stone cargoes on an 'S' Class has an average Specific Gravity of 1.034, whereas for screened stone cargoes on an 'A' Class, the overflow Specific Gravity is 1.043. The greater the density contrast between the overspill jet and the water column (Specific Gravity of seawater 1.026 @ 15^{o}C), the more intense the development of the a 'Density Current' will be and hence accelerate the settling of the overspill sediment to the seabed, allowing less advection away from the dredge site. Straightforward Gaussian diffusion modelling techniques will not take into account this contrast, and hence tend to further overestimate the extent of plume excursion.

The verification of numerical models using competent field data is essential for realistic appraisal of the impacts of dredging operations. Without such data, responsible numerical modelling must be based on the 'Precautionary Approach', a worthy principle which may unfortunately lead to unnecessary sterilisation of workable reserves, and unwarranted concern on the extent of potential impact on the surrounding environmental resources.