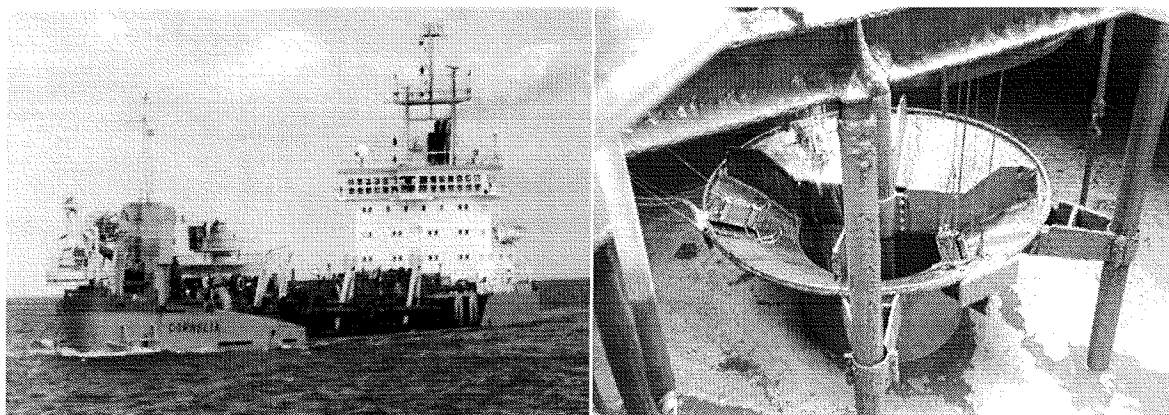


Delft University of Technology
Faculty of Civil Engineering and Geosciences
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Overflow sampling of Trailing Suction Hopper Dredgers

A case study on TSHD Cornelia, June 2002



M.Sc. Thesis
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February 2004.


TU Delft

Faculty of Civil Engineering and Geosciences


VBKO
VERENIGING VAN
WATERBOUWERS EN BAGGER-
KUST- EN OLVERWERKEN

This graduation study is carried out under contract to Vereniging van Waterbouwers in Bagger-, Kust- en Oeverwerken, VBKO.

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The supportive data can be found in the corresponding appendix “Overflow sampling of Trailing Suction Hopper Dredgers, A case study on TSHD Cornelia, June 2002”.

Abstract

Turbidity is recognised as one of the major environmental problems of dredging. To get a handle on this problem the Dutch dredging industry (VBKO) commissioned a research project to develop software capable of predicting how much sediment is released into suspension during dredging operations.

Major field measurement exercises are carried out in order to provide calibration data for the software. One exercise has been carried out using a trailing suction hopper dredger (Cornelia) working in the port of Rotterdam in June 2002. During dredging by a trailing suction hopper dredger one or two suction pipes are lowered on the seabed. A mixture of sediment and water is sucked up and passes into the hopper of the dredger. When the hopper is loaded beyond capacity, excess mixture leaves the hopper by means of the overflow and is released back into the water. This overflow of sediment is the main contribution to the sediment plumes near the dredging vessel.

The main objective of this thesis is to find out whether the flow rate and the solids concentrations leaving the dredging vessel can be calculated sufficiently from the measured overflow samples.

Special techniques were developed to sample the hopper overflow. Three novel flow-through samplers are constructed to sample the overflow mixture. These have been used, in combination with a bottle sampler to obtain about 500 samples taken at four different locations in the overflow during 14 trips. All samples have been analysed on particle size distribution and dry matter content, some samples also on particle specific gravity.

Soil samples taken in the dredging area provide the data needed for mapping the soil conditions coming up by the suction pipes. It appears that at some locations quite homogeneous soil conditions are present. Nevertheless also significant variations in the Particle Size Distributions have been found.

During all dredging operations, the vessel's TDS (Tonnes Dry Solids) system has logged the characteristics like draughts and the concentrations plus velocities of the upcoming mixture in the suction pipes. These data have been reviewed to assess their reliability. After recalibration of the datasets, the concentration leaving the vessel by the overflow is computed by using sediment balances. The computed sediment releases have been compared with the measured overflow releases in order the attempt to validate the sampling method. It appeared that validation of the samples by this comparison was not possible.

The results of all samples taken are analysed also statistically, focussing on the correlation between the different samplers for each individual trip and a batch analysis of all trips together. In addition, the samples are also investigated by physical means focussing on the impact on the measurements of overflow level variations, the vessel's movements and the sedimentations process in the hopper. From these analyses conclusions are drawn and recommendations are made. The main conclusions are:

- The amounts of particles discharged by the overflow during a trip can be calculated using the parameters obtained from the samples taken at the overflow. The accuracy of these computations is not known exactly but it is estimated to be approximately $\pm 25\%$.
- The computation of an average Particle Size Distribution of the overflow is also possible by using the parameters obtained from overflow samples. However rather large fluctuations are found. Focussing on the fine particles like d_{10} values only, quite consistent results are obtained. This finding is encouraging since the fine particles are considered to be the main contribution to the sediment plumes in the vicinity of TSHD.
- The flow-through sampler is preferred to sample the overflow. The level of accuracy of the TDS system is not sufficient to compute reliable sediments losses at the overflow.

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List of relevant terminology

The vessel's draught

The distance from the lowest part of the vessel to the average water surface.

Ullage table

The Ullage table shows the relation between the level of the mixture in the hopper and the volume of this mixture.

Carène diagram

The Carène diagram shows the relation between the vessels draught and trim to the displacement of the vessel.

Overflow / Weir

The overflow is the facility in the hopper where the redundant mixture is discharged from the hopper when the hopper is being filled beyond capacity.

Starboard side

The right hand side of the vessel when facing forward.

Portside

The left hand side of the vessel when facing forward.

The lander

The lander is the place in the hopper where the suction pipes discharge their mixture.

TDS-system

The TDS system is an automated system that calculates the load of the hopper, expressed in Tonnes Dry Solid. The load is computed using data obtained by online monitoring of the vessel's characteristics including, draughts and level of the mixture in the hopper. Moreover the system monitors the velocity and density of the incoming mixture in the suction pipes.

Abbreviations

VBKO: Vereniging van Waterbouwers in Bagger-, Kust- en Oeverwerken.

FTS: Flow-through samplers.

BS: Bottle samplers.

TDS: Tonnes of Dry Solids

TSHD: Trailing Suction Hopper Dredger

LMOB: Lean Mixture Over Board

List of symbols

Roman symbols:

Symbol	Definition	Unit
A_p	Suction pipe area.	m^2
$C_{s2,av}$	Average concentration of the mixture of the two suction pipes.	tonnes/ m^3
$C_{o,av}$	Average concentration released by the overflow.	tonnes/ m^3
C_{vg}	Volume concentration of soil particles.	%
d	Draughts of vessel.	m
$d_{carène}$	Input draught for the Carène diagram.	m
d	Grain diameter	μm
D_p	Diameter suction pipe.	mm
h	Level of mixture in the hopper.	m
$h_{average}$	Average level of mixture in the hopper.	m
$H_{overfl.}$	Overflow level.	m
H_{ref}	Reference level.	m
$M_{s, cum.}$	Cumulative mass of sucked mixture.	tonnes
$M_{o, cum.}$	Cumulative mass released by overflow.	tonnes
$M_{s,av.}$	Average mass mixture sucked by suction pipes.	tonnes
$M_{displ.}$	Tonnes of displacement.	tonnes ($\rho_w = 1.02$ tonnes)
Q_{s1}	Discharge of one suction pipe.	m^3/s
Q_{s2}	Discharge of two suction pipes together.	m^3/s
Rho load	Specific density of the mixture in the hopper	tonnes/ m^3
TDS_{s2}	Tonnes of dry solids by two suction pipes.	tonnes
$TDS_{suction}$	Tonnes of dry solids by two suction pipes.	tonnes
TDS_{hopper}	Tonnes of dry solids stored in the hopper.	tonnes
t_{ess}	End steady state situation.	hrs
t_s	Start suction.	hrs
t_o	Start using the overflow.	hrs
u	Velocity in suction pipe.	m/s
V_{hopper}	Volume mixture in hopper.	m^3
$V_{s, cum.}$	Cumulative volume sucked by suction pipes.	m^3
$V_{o, cum.}$	Cumulative volume released by overflow.	m^3
V_l	Volume load hopper.	m^3

Greek symbols:

Symbol	Description	Units
α	Vessels trim	-
β	Angle of current approach at Side flow through sampler	grades
τ	Time delay	s
Δt	Sampling rate	s
ρ_g	Specific density of grain	tonnes/ m^3
ρ_l	Specific density of load in hopper	tonnes/ m^3
ρ_w	Specific density of sea water	tonnes/ m^3
ρ_s	Specific density of sucked mixture	tonnes/ m^3
$\rho_{s1, SB}$	Volumic mass mixture suction pipe (Star board side)	tonnes/ m^3
$\rho_{s1, PS}$	Volumic mass mixture suction pipe (Portside)	tonnes/ m^3

1 Introduction

1.1 Backgrounds

During the dredging process, sediment plumes develop in the vicinity of the dredging vessel. These plumes can cause damage to the ecosystem because of the reduced light penetration, increased concentration of suspended solids and sedimentation. In 1997, the VBKO¹ and the North Sea Directorate started a software development project. The purpose of this project was to develop a calibrated software package, which can be used to derive realistic estimates of sediment release during dredging and disposal. The execution of the project, TASS (Turbidity ASsessment Software) was awarded to Hydraulic Research Wallingford (HRW) in association with Dredging Research Ltd (DRL).

Because dredging can be executed by several methods, the software has to be developed for every single method. There are five major dredging techniques: Grab, Backhoe, Bucket ladder, Cutter-Suction and Trailing Hopper Suction. The use of this last technique has increased tremendously in the last two decades. At this moment preliminary TASS modules for these five different methods have been developed but because of a lack of data they have not been calibrated and the models are therefore not ready for use. In order to finalize the TASS project, calibration of these software modules has to be done.

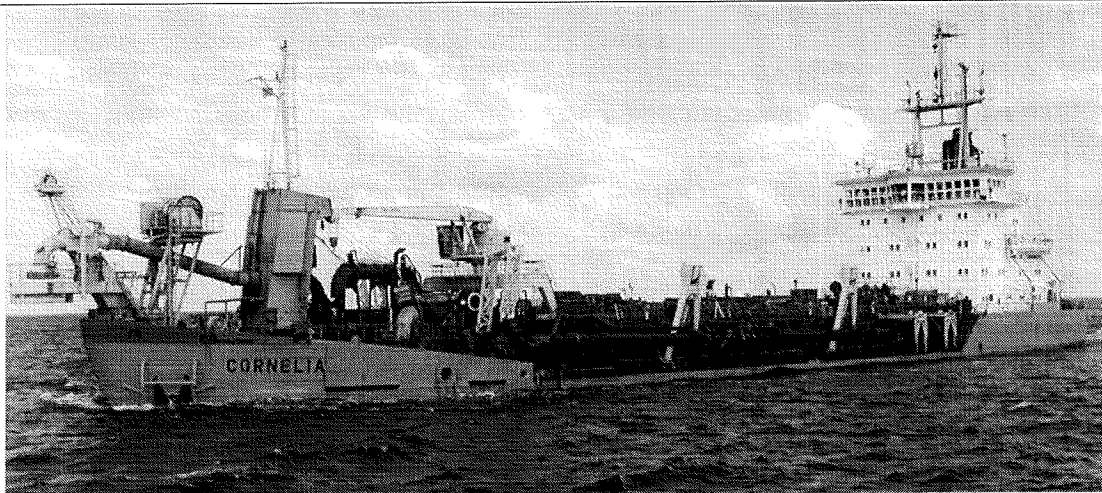


Figure 1-1, the TSHD Cornelia, fully loaded.

When they are calibrated, the TASS software modules will provide estimates of the quantity of sediment released by the dredgers. These quantities will be the input for the

¹ Vereniging van Waterbouwers in Bagger-, Kust- en Oeverwerken

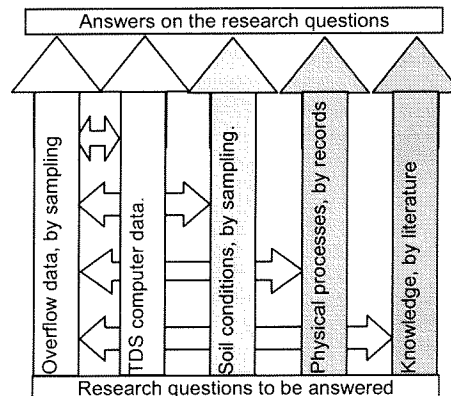


Figure 1-2, the obtained data sets during the field trial.

1.2.3 Research objectives

All research starts with the development of the research objectives, which guide the research process. Some appear to be hard to answer; some cannot be answered at all. Nevertheless the attempt to answer the questions increases the understanding of the processes that are related to these questions.

Main question: Can the Particle Size Distribution and the solids concentration leaving the dredging vessel during dredging operations be calculated sufficiently accurately from parameters measured in overflow samples and the monitored data of the TSHD processes?

1.2.3.1 Sub questions

1. Which sampling technique is preferred for measuring campaigns in the near future?
2. Are the TDS monitoring systems of both the contractor and the North Sea Directorate sufficient to predict the sediment concentrations leaving the TSHD during dredging, or is the overflow sampling method required?
3. Is it necessary to sample the overflow at more than one location and, if so, which locations are preferred?
4. What number and size of samples is the best, is it possible to reduce the sampling rate, without losing valuable information?
5. Is it possible to determine which processes on a TSHD are most important with respect to the computations of the composition of the overflow losses (sensitivity analysis)?

These 5 research questions are extensively reviewed at the end this thesis, chapter 12 "conclusions and recommendations".

1.3 Stakeholders

The stakeholders include all parties that were directly and indirectly involved during this measuring campaign. The following organizations were involved in the campaign:

- VBKO.
- North Sea Directorate.
- Boskalis, owner of the vessel.
- HR Wallingford.
- Dredging Research Ltd.
- US Army Corps of Engineers.

The key project personnel who were directly involved in the planning and execution of the measurements were people from these organizations and companies. In addition to the personnel on board the vessels during the campaign itself, many other parties were involved to realize the campaign. For the names of those people one is referred to HR Wallingford / DRL Report EX 4908, 2003 [ref].

1.4 The report

This thesis report can be divided into three parts. The first part (Chapters 1-5) focuses on all data that was collected during the field trial. The second part (Chapters 6-8) examines what the data are telling us. The analysis of the data is performed in the third part of the report (Chapters 9-11).

Chapter 2 describes all parameters that were monitored during the field trial. In addition, the measuring devices are briefly evaluated including the TSHD itself. Chapter 3 focuses on the measurements of overflow composition and the samplers are evaluated in detail. In addition to the overflow composition, the soil conditions in the dredging areas were investigated. The results of the analyses of the soil samples are reviewed in chapter 4. The overflow and seabed samples were analysed by TNO-NITG. Chapter 5 reviews the methods of analysis. Chapters 6,7 and 8 focus on the physical processes during the dredging. In Chapter 6 the video records are reviewed, chapter 7 examines into the calibration of the TDS monitoring system and, in chapter 8, an attempt is made to set up a mass balance.

In chapter 9 where the results of the overflow measurements are analysed without performing any computations with this data. In chapter 10 the overflow sampling results are analysed by basic statistical computations. In chapter 11 the hopper trap efficiency and the incoming flow conditions are related to the results of the samples taken at the overflow. In this chapter almost all data collected during the field trial is used. In the final chapter the research questions as stated in this chapter are reviewed and recommendations for future measuring campaigns are made.

Length o.a.:	112.8 m
Breadth:	19.6 m
Draught:	7.5 m
Loading capacity:	8426 tonnes
Hopper capacity coaming:	6,617 m ³
Total installed power:	7,800 kW

They were mainly occupied with the calibration of the TDS system but they were also responsible for the communication with the ships crew, the sampling crew at the overflow of the vessel and the survey vessel that was used to collect additional data that are not considered in this report. The TDS calibration procedures are reviewed in chapter 7.4 of this document.

3.2 The samplers

Three Flow-through samplers and one Bottle sampler were used. A guiding system for the Flow-through samplers was mounted on the overflow funnel. The position of the bottle sampler varies in three dimensions for every sampling action. In this paragraph, the sampling locations and the design and dimensions of both types of sampler are reviewed. The corresponding drawings of the Flow through samplers are presented in Appendix 3.1.

3.2.1 Position of samplers

The flow through samplers had a fixed position on the overflow but the position of the Bottle sampler varied during every sampling action (Figure 3-2). The operator simply lowered the bottle sampler in the centre of the overflow using a rope. However the overflow current dominates the position of the sampler, therefore it is not known exactly where the samples were taken. In chapter 11.2, the positions of the samplers are reviewed further.

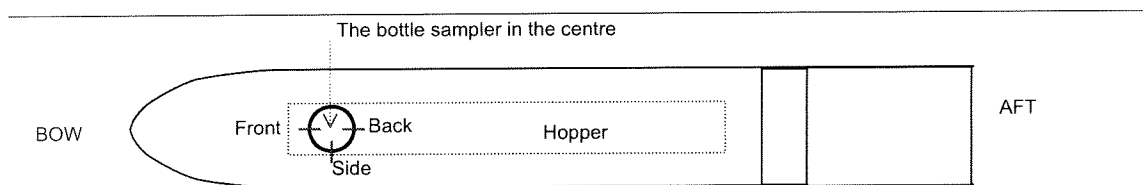


Figure 3-2, sketch of position of the overflow samplers.

3.2.2 The flow through samplers

Often the flow-through samplers are referred to as iso-kinetic samplers. One should bear in mind the aspect ratio of these samplers is probably too great to call them really iso-kinetic.

In Figure 3-3 the aspect ratio is explained further. The thickness of the sampler's body and the elastic bands, which are used for closing the sample doors probably influence the measurements. These disturbances causes extra turbulence and contraction of the streamlines, therefore it is preferred to call these samplers Flow through samplers rather than iso-kinetic samplers.

The Flow through samplers consists of three parts, the sampler body, the sled (which carries the sampler body) and the guiding system. In the following paragraphs these sampler parts will be further reviewed.

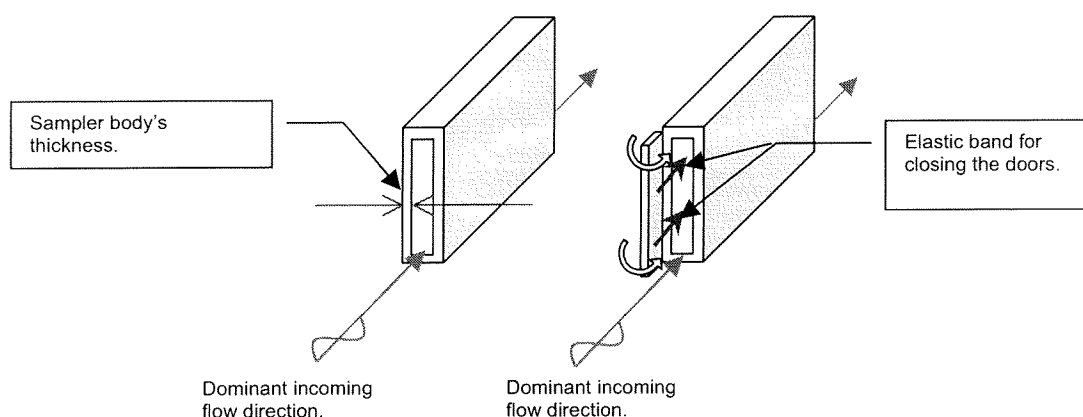


Figure 3-3, two examples of aspects that influences the iso-kinetic measurements.

3.2.2.1 The sampler body

The body consist of a rectangular tube with internal dimensions of approximately 390 mm long, 200mm high and 50mm wide. The sample volume is about 4 litres. Closing doors are fitted to both ends of the body. When the sampler body is placed on the sled, the doors are opened and held open by pins that locate into steel uprights on the sled. The doors are closed by strong bungees when the pins are released. The release cord is designed so that the back door closes fractionally before the front door. Both doors are sealed with soft rubber seals to prevent any loss of sample.

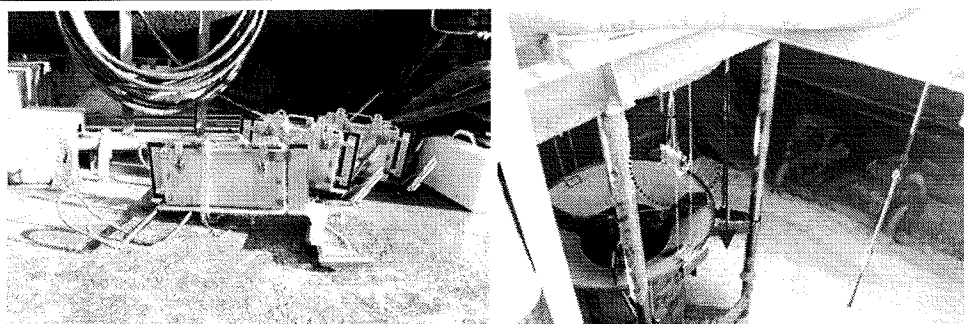


Figure 3-4, the Flow through sampler (left) and the Aft sampler moving down along the ropes (right).

The sampler body clamped on the sled between two vertical locator plates. The clamping mechanisms are not shown on the drawings in appendix 3.1, however they consist of thin steel straps with a quick release mechanism

3.2.2.2 The sled of the Flow-through samplers

The travel mechanism of the Side Flow-through sampler diverges from the Front and Aft Flow-through sampler's mechanisms.

A steel sled carries the body of the side sampler. This stainless steel base plate with two skids underneath (made of steel rod) enable the sled to rise over the lip of the funnel as it is deployed and then to 'sit' in the funnel at the correct angle.

The skid also permits easy retrieval of the sampler, back over the lip of the funnel, when the sample has been taken. Two vertical steel plates hold the sampler body in position. A third steel plate near the front of the sled acts as a flow guide (the counterpart of the open front door of the sampler body).

A travel mechanism is mounted on the sled comprising two steel tubes that run along nylon guide ropes. The tubes are joined at the front by a thin steel plate. At the back they are joined by steel rod.

The steel rod is part of the simple hinge mechanism that joins the traveller to the sled. It is essential that the traveller and the sled are hinged or they will be severely damaged as the sampler is deployed and recovered over the lip of the overflow funnel.

The front and aft samplers are operated from access platform above the overflow.

Therefore the samplers move only in vertical direction and no sled is required. This is shown in the right picture of Figure 3-4, the stainless steel base plate with the sampler on top moves along two nylon guide ropes. Because of the fact that the samplers were moved only in vertical direction they are much easier to operate than the side sampler.

3.2.3 The bottle sampler

The bottle sampler consists of a bottle, which is placed vertically in a steel container. When it is positioned at the sampling point, by pulling a rope the bottle is opened. The filling time varies from about 2 to 6 seconds, depending on the bottle orientation and overflow velocity. After the bottle is filled, the sampler is pulled back and the contents of the bottle are released in one of the containers.

3.3 Sampling procedures

3.3.1 Sampling procedure by using flow through Side sampler

In this paragraph the sampling procedure of the side sampler is reviewed. The procedures of the Aft and Front samplers appeared to be identical. Because these samplers moved only vertically, 2 persons could operate these samplers instead of the three operators that were needed to handle the side sampler.

The sampling procedure was as follows:

1. First Operator A opened the doors of the sampler than the sample body was placed on the sled.
2. The sled was allowed to slide down two ropes, which extended from the hopper coaming (side sampler) or from the access platform (fore and aft samplers) to the overflow funnel. In the case of the side sampler, operator B was required to tension these guide ropes. This was not necessary for the other two samplers. The Operator C was responsible for the pin-release cord and the recovery rope.
3. When the sampler was in position, Operator C closed the doors of the sampler by pulling sharply on the pin release cord. Operator A recorded the exact moment of closure.
4. Operator C pulled the filled sampler back up the ropes to the edge of the hopper or the access platform while Operator B maintained the tension on the ropes (side sampler only).

5. On deck the sampler body was removed from the sledge by Operator A and was washed to remove any sediment sticking to the outside. The sample was then carefully decanted into a large bucket. Exactly 1 litre of clean water was used to wash any adhering sediment from inside the sampler. Sometimes more water was used or some sample was spilled, all abnormalities were recorded on the timesheet.
6. The clean sampler was then replaced on the sled, ready for a new sequence.

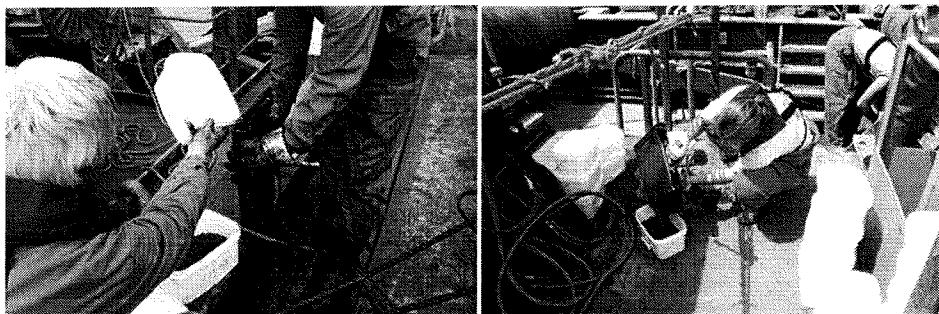


Figure 3-5, decanting the flow-through sampler.

3.3.2 Sampling procedure bottle sampler

The sampling procedure for the bottle sampler was as follows:

1. First the plastic bottle was placed in the steel container (cylinder).
2. The operator lowered the sampler down by a rope into the overflow.
3. The sampler was positioned as good as possible in the centre of the overflow funnel at a depth of about 30 cm (based on the video records and from interviews with the operators).
4. By pulling on a second rope the steel lid of the container opened and the overflow mixture was captured by the bottle. The opening time is not defined in the protocol.
5. After the bottle is filled, the lid was closed and the sampler was pulled back to the access platform.
6. The content of the bottle was carefully decanted into a small bucket. Exactly 0.5 litre of water was used to wash any adhering sediment from inside the bottle.
7. The clean bottle was then replaced in the container, ready for a new sequence.

3.3.3 The sampling rate

The general rule applied to the sampling frequency was to sample as often as possible. However, using the system employed during the trial, it was found that each sample took approximately 3 to 4 minutes to obtain, including decanting the sampler into the container and cleaning the sampler before re-deployment. Because of practical reasons the side sampler was the most difficult one to sample. The bottle sampler was obviously easier to manage; therefore the sampling rate was higher.

The duration of the overflow period depended on the material being dredged. During sand trips overflow periods of 40 minutes were common. When dredging mud the overflow periods were 10 to 15 minutes. With four sampling crews in action, during sand trips about 40 to 55 samples were taken. During dredging mud, 15 to 30 samples were obtained.

4 Sampling the dredging areas

This chapter reviews the soil conditions in the dredging areas. The different methods used for sampling are described followed by a presentation of the results of the particle size distribution analyses. These are assessed to establish their consistency and the spatial variations in each dredging area.

In the end of this chapter the results are reviewed whether they are useful for further research. In such research a relationship will be established between the particle size of the material that enters the hopper and the particle size of the material leaving the hopper through the overflow (Chapter 11).

4.1 The sailed tracks and sample areas

The tracks sailed by the TSHD during the measuring campaign were logged by the on-board GPS system. Together with these track data also the dredging status was stored into one track-file. Appendix 4 shows the results of these track-files plotted into separate drawings for each sailed track. The colour of the plotted track-line shows the status of the TSHD: the light blue line indicates "empty sailing", the red line indicates "dredging", and the dark blue line indicates "loaded sailing". The soil sampling locations are also plotted on these drawings. These sampling locations can be useful in some cases. For instance the samples taken at the Maasgeul, were taken exactly on one of the tracks, sailed during the campaign. If the spatial variations between the sample positions are small, or when they show a trend along the track-line of the vessel, it may be possible to make realistic assumptions about the characteristics of the soils sucked into the suction pipes.

4.2 Soil sampling techniques used

As stated in the introduction paragraph of this thesis report, both Box corers and the Free fall corers have been used to sample seabed. In this paragraph both sampling methods will be discussed briefly.

4.2.1 Boxcorer sampler

The Boxcorer sampler (Figure 4-1) is a gravity-type sampler developed for taking undisturbed surface samples. This sampler is very suitable for taking samples in the deep-sea areas, because of the way the sampler works. The corer consists of a square tube, open on both sides. Heavy weights force the tube into the bottom for several decimetres. When the tube is settled in the bottom the sampler is recovered. A steel cover plate closes the bottom opening and the sample is captured in the tube. On board, the sub-samples were taken from the upper and lower 20 cm of the undisturbed sample. Both sub samples were analysed by TNO-NITG separately (Chapter 5).

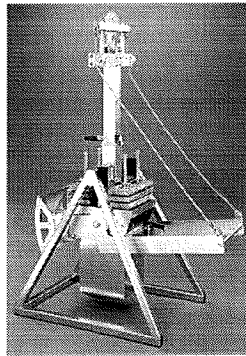


Figure 4-1, example of a Boxcorer sampler.

4.2.2 The Free fall corer sampler

The Free fall corer sampler (Figure 4-2) is dropped from a distance above the seabed. When the tube reaches the bed it penetrates by kinetic energy. When the sampler is settled, a lid on top of the tube closes. This causes an under pressure between the top of the taken sample and the steel lid which helps to retain the sample in the tube. Because the penetration capacity of the Free fall corer sampler is much less than that of the Box-corer sampler, the Free fall corer sampler was only used for silt soils.

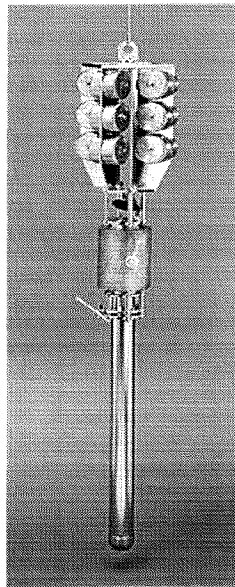


Figure 4-2, example of a Free fall corer sampler.

4.2.3 Techniques and locations

As noticed the penetration capacity of both sampling methods diverged, therefore not for all sampling locations both methods of sampling were used.

For sand soils only the Box corer sampler was used however, Table 4-1 shows that both methods were applied at the Maasmond area. This can be explained by the fact that no guidelines for which sampling technique was to be used were available for the sampling personnel on board of the survey vessel. Since both sand and silt soils were present at the Maasmond area, both methods were applied.

Sampling location	Method of sampling		Amounts
	Boxcorer	Free fall corer	
Maasmond (E and F)	X	X	40
Sand Pit 5 (11 to 19)	X		20
Maasgeul (A-B 5 to A-B 9)	X		10
Verdiepte loswal (A-B 1 to A-B 4)	X		8

Table 4-1, samplers applied in different areas.

4.3 Results

In the corresponding appendix 4.1 and 4.2, the sampling locations and the dredged tracks during the trial are plotted into maps. Moreover in appendix 4.3 all the particle size distributions (PSD's) of the soil samples are displayed per sampling area into figures.

In this paragraph the homogeneity of the seabed at the intake areas will be reviewed. In addition, the sailed tracks by the vessel related to the sampling locations will be discussed. The classification of the results is based on the Wentworth scale [Wentworth, 1922].

4.3.1 Two layers analysed

All samples were divided into two layers on board of the survey vessel. With a penetration depth of about 40 cm, two layers of 20 cm each were obtained.

For this specific research the second layer is considered to be the most representative one, because the dredging depth was 20 to 40 cm at the sand soils areas. This dredging depth has been estimated by DRL from the side scan sonar plots. It should be noted that the decision for taking only the second layer into account should be reviewed more extensively during future research.

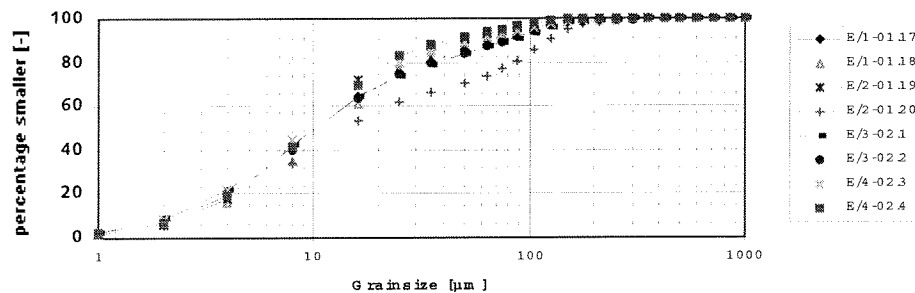
4.3.2 Results Maasmond samples

The samples taken by the samplers are characterised by the Particle Size Distributions (Appendix 4.3). Most of the shapes of the PSD curves obtained in the E area of the Maasmond (shore side of the Maasmond) can be characterised by a flat head, a steep centre part and again a flat tail (The first layer of 20 cm is labelled for the Maasmond series (E and F) by the highest number of the sampler location label (Figure 4-3).

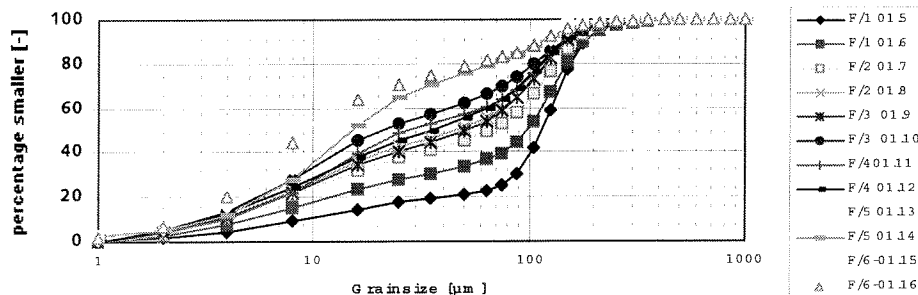
However also bimodal samples are obtained, these curves do not show the characteristic flat-steep-flat curves (for example sample E/2-01.20). One should notice, showing the PSD's of 6 different locations in area E, on every spot two layers were analysed separately, resulting in two PSD curves per sampling location. The d_{50} of the

samples taken in this area varies from of 8 to 20 μm . This small bandwidth indicates that in this area quite homogeneous soil conditions are present.

Intake area Maasmond Boxcorer E_series



Intake area Maasmond Boxcorer F_series



Note: The first layer of 20 cm is labelled for the Maasmond series by the highest number of the sampler location label.

Figure 4-3, PSD's taken at the shore site of the Maasmond (E series) and off shore site (F series).

The bandwidth of samples taken at the off shore site of the Maasmond (the F-series) is significantly larger than the bandwidth of the E-series this is caused by the presence of more coarse material which is probably deposited by the sea (Figure 4-3). The results further reviewed we find that the samples becomes almost progressively coarser towards the sea (the sampling locations are plotted in appendix 4.1, trip 8). Only the location of sample F/1 is doubtful. Again also bimodal samples are obtained (F/6 for example).

Although the progressive increase of coarse material in sea-ward direction a relationship between the particle size of the material that enters the hopper and the particle size of the material leaving the hopper through the overflow is difficult to establish. The results (presented in appendix 4) between the two layers for every sample diverge (d_{50} range of 40 μm) and also the results by the both sampling methods vary (d_{50} range of about 40 μm).

The silty-sea bed conditions of the E series are quite homogeneous, it might be possible to extract one representative PSD for this area.

4.3.3 Results Sand Pit no. 5 samples

In Pit 5 (Appendix 4.1) 10 samples covering the whole area were taken using the Boxcorer. The results show a rather homogeneous soil condition. Again the samples were divided into two parts of 20 cm each. The consistency of both layers occasionally diverges significantly at this dredging area. Figure 4-4 displays the variations of the d_{50} values of both layers. The variations for instance shown by Sample 5-12 are rather suspicious if we consider that the spatial difference between the two layers is only 20 cm.

As the whole sampling area is concerned, no spatial trends (in vertical and horizontal direction) or relations in-between the different sampling location are obtained when analysing this data.

Two layers by Boxcorer- D_{50} values Sand pit no.5

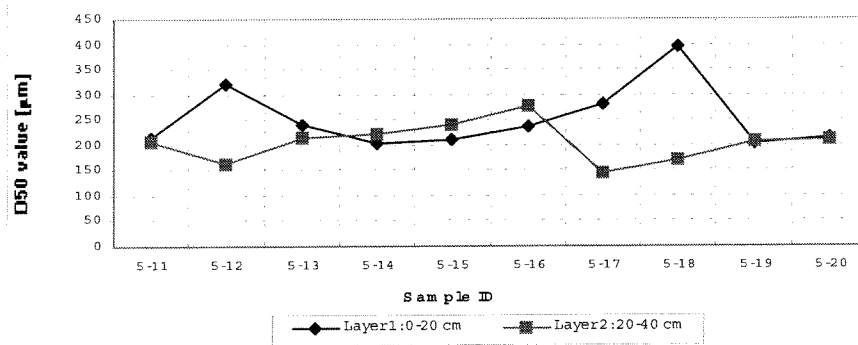


Figure 4-4, d_{50} variations in the vertical layers.

4.3.4 Results Maasgeul samples

Five Boxcorer samples were taken in this area (Appendix 4.1, trip 107). The d_{50} of the samples varies from 150 to 350 μm and the shapes of the PSD's of these samples do not show any consistency. Furthermore no spatial trends or relations are obtained. Because of the lack of any consistency in the sampled results, it is also in this dredging area not possible to use these data to characterise the incoming soil conditions while dredging.

Intake area Maasgeul B_series

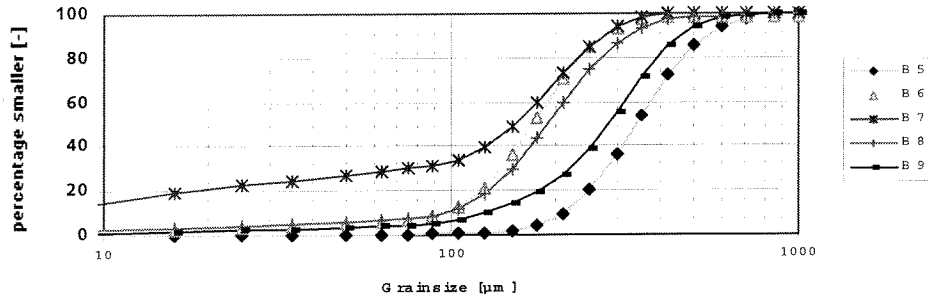


Figure 4-5, PSD's of samples taken at the Maasgeul.

4.3.5 Results Verdiepte Loswal samples

At the Verdiepte Loswal (sandpit 6) location only 4 Boxcorer samples were taken. Although the number of samples is small, the results presented in Figure 4-6 show a rather homogeneous soil condition. The conditions appeared to be even more homogeneous than the soil conditions at sandpit 5. All samples can be classified as fine sand [Wendworth 1922]. Moreover no bimodal samples were found. These quite homogeneous soil conditions makes this area also suitable for characterising the mixture dredged by the TSHD (see chapter 11). Knowing the in-situ soil conditions, a comparison can be drawn between the particle sizes coming into the hopper and the particle sizes discharged by the overflow. This comparison can lead to a better understanding of the sedimentation process in the hopper thereby overflow sampling results can be related to the existing sedimentation theory. Both aspects can be used in validating the sampling results.

Sand intake area Verdiepte loswal B_series

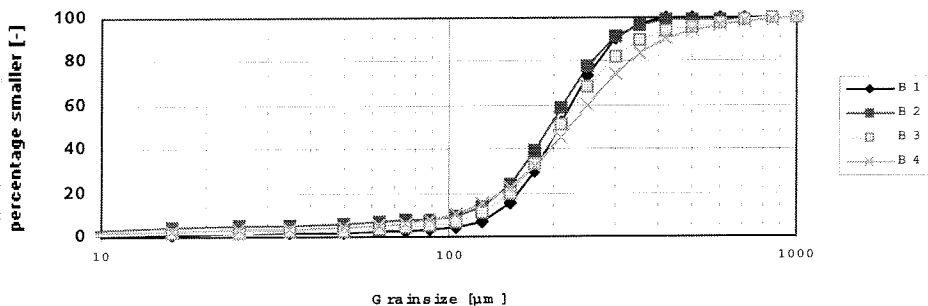


Figure 4-6, Boxcorer samples of second layer Verdiepte Loswal.

4.4 Conclusions on analysis of sea bed samplers

From this analysis the following conclusions can be drawn:

1. The soil samples taken in the off-shore silt-sand area (Area F) of the Maasmond become progressively coarser towards the sea.
2. The grain size parameters for the sampling area Maasmond situated off shore (appendix 4.3, the F-series) are the most highly variable of all sampling areas. Although the large bandwidths an almost progressive increase of coarse material in sea ward direction is obtained.
3. With the exception of the Maasmond F-area, no spatial relations could be identified in all dredging areas. Even in the sample vertical, no relations are obtained.
4. Sandpit 6 (Verdiepte Loswal) and Sandpit 5, shows up the most homogeneous soil conditions, that makes these areas valuable for further research (chapter 11).
5. The samples taken at the Maasgeul were taken exactly on the track (appendix 4.1) of the vessel after the measuring campaign (commissioned by the campaign direction). However the spatial variations between the different samples are significant and this exact track match therefore does not add any values to this research.

From the sub-conclusions stated above one can conclude regarding to the sand soils, almost no spatial relations in horizontal or vertical directions were obtained. Only the 4 sand soil samples taken at the of the Sandpit 6 and the 10 sand samples taken at sandpit 5 showed up quite consistent values. Bringing the in-situ soil conditions into account for the remaining tracks is therefore very difficult.

In chapter 11.2, a relation is drawn between the in-situ soil conditions and the overflow measurements of Sandpit 6. Sand pit 6 was chosen because these results appeared to be most homogeneous of both areas. In future research it is also worth to draw up the relation between the soil conditions of sandpit 5 and the overflow measurements.

5 TNO analyses of all samples

All samples taken during the measuring campaign in June 2002 were analysed at the Department Geo-Marine and Coast of the Netherlands Institute of Applied Geoscience TNO (TNO-NITG). In this chapter and the associated appendix, the approach and methodology of the different types of analysis are described and the different analyses will be reviewed briefly for their reliability and consistency. For more extensive information, one is referred to the TNO report "Grain-size, dry-matter content, and particle-specific gravity of seabed and dredger-overflow samples, NITG 03-197-C" [ref.].

5.1 Approach and methodology

The dry matter analyses and the particle-size distributions (PSD's) provided by TNO are fundamental for this research. In total 78 seabed and 466 overflow samples were analysed. The grain size was measured using a Malvern laser particle sizer. Two overflow samples were sub-sampled in duplo in order to check whether the sub-sampling procedure used in the laboratory results in representative sub-samples. Two additional overflow samples were sub-sampled both in the middle and on the side of the plastic containers filled with the overflow sediments in order to check if grain-size distribution is uniform within the containers. The dredger-overflow samples were also analysed for their dry-matter content.

Finally, 2 seabed and 6 overflow samples were analysed for their particle-specific gravity. However this characteristic has not been taken into account during this research.

For the determination of the concentration and PSD's of the samples, different approaches and methodologies were applied. These approaches are based on the NEN 5753 and are presented in appendix 6. Pictures taken during the laboratory activities illustrate some of the procedures followed.

5.2 Conclusion on reliability

5.2.1 Samples taken in duplo

The sub-samples measured *in duplo*, 11F-111 and 12F-124, showed comparable grain-size distributions. Important grain-size parameters such as fraction < 63 μm , d_{10} , d_{50} , d_{60} , d_{90} and d_{60}/d_{90} are almost identical. The sub-samples taken from different parts of two plastic containers, 8zij-47² and 8C-75, showed that the grain-size distribution is not uniform within the container, and thus that a representative sub-sample must consist of a mixture of sediment taken from different positions within the container.

² Both Zij as Side are used for labelling the Side samples

5.2.2 Dry matter

By using the entire sample, the error associated with these measurements is minimised. As stated in appendix 5.1, a constant uncertainty is associated with assumed salinities. For the first few samples, the salinity was estimated. This results in larger errors for samples with a low dry-matter content than for those with a medium to high dry-matter content. This problem does not play a role in those samples for which the salinity was measured in the laboratory. Maximum measurement uncertainties of 5 g on the scale used to determine the mass of original samples (with and without water) in their plastic containers result in maximum uncertainties of 0.3% (for samples with low dry-matter concentrations).

5.2.3 The Malvern-analyses

By using the Malvern-analyses the entire Particle Size Distribution of a sample can be measured. When the appropriate pretreatment procedure is applied, Malvern-analyses are very reliable. Differences with the results from other types of measurement, such as sieving and pipette analyses, can be ascribed to the effects of grain shape (Konert and Vandenberghe, 1997) [ref.]. To compensate for these differences, a correction can be made if desired. The samples analysed within the framework of TASS consist of a sand-mud mixture. For such mixtures, the reliability of the measurements has not yet been determined. They pose several problems, including: 1) representativeness of the material selected from the sub-sample for the Malvern-analysis, and 2) reliability of the model (with absorption coefficient and refractive index) used to convert laser measurements into grain-size distributions. At this moment, a study is being finalized at TNO-NITG that shows well-constrained error margins for this type of analysis. Comparison between *triplo* Malvern and pipette measurements reveals that the correspondence is best when the Malvern analyses are performed on pretreated samples, without the use of ultrasonic conditions. For all but the finest fraction ($< 2 \mu\text{m}$), the correlation coefficients are very high.

5.3 Recommendations

5.3.1 Storage of samples during measuring campaign

The overflow samples taken during the field trial were stored into two types of containers (Figure 5-1). Most of the centre overflow samples were stored into small 2-litre-sized circular containers, as displayed on the right side of Figure 5-1. The rest of the samples were stored into rectangular 6-litre containers. These last-mentioned containers are not recommended for future field trials because the covers appeared not to seal sufficiently. Consequently, water will more easily evaporate from the sample. It is recommended to perform a safety measure directly after sampling, so that we can measure afterwards whether water is evaporated. An other solution can be found by using simply to seal sample containers with plastic tape (standard practice in soil investigations).



Figure 5-1, the containers with the overflow samples.

5.3.2 Stepwise commissioning

Because of budget problems, a stepwise commissioning was employed. First, 2 tracks were analysed; subsequently, another 4 tracks were processed. During a final commissioning round, the remaining 8 tracks were analysed. In future field trials it is recommended that all (properly taken) samples are analysed immediately. The cost of the analyses is low compared to the cost of taking the overflow samples at sea. One should decide in advanced how many samples are going to be collected.



6 Video monitoring

During the measuring campaign camera's recorded some of the measuring procedures (processes). About half of the video records were made on the Cygnus, a Zuid-Holland Directorate survey vessel. The rest of the records were made on the Cornelia (Boskalis TSHD). All original records were copied on two VHS videotapes. In this chapter the processes shown by these tapes will be described and briefly analysed.

6.1 Available records

One tape is a record of the movements of the survey vessel Cygnus relative to the Cornelia during side scan sonar data collection. The sonar data were used to study the development of the initial sediment plume underneath the TSHD. During these specific plume observations the Cygnus moved from the stern to the bow of the Cornelia, while she was dredging. The camera was positioned at a fixed point on the Cygnus aimed at a beacon on the other side of the Cygnus. The time-stamp on the video records enables the exact position of the Cygnus relative to the Cornelia to be obtained. Air bubbles and sediment in suspension caused by the drag head, were clearly visible on the sonar records. During one of these sessions, one person was standing in front of the camera, that made the records useless for further research.

The second videotape contains more valuable information for the analyses of the overflow samples. Unfortunately no real time (sample_cam 1A1), registration was performed (and the time stamp on the records were missing). Moreover the camera was not positioned on a fixed place so that all the four samplers were recorded at once. Because of this lack of information, the current regime around the overflow bell mouth shown by the video records at a specific moment in time could not be coupled to the measured values of that moment.

6.2 Position of the Flow through samplers

All three Flow-through samplers were positioned on a fixed point on the overflow. The absolute vertical variation of the overflow is not known exactly, because the overflow level sensor was not calibrated during the measuring campaign (see chapter 7.3.2.1). Nevertheless, the qualitative variations are extracted from the TDS records (see appendix 9). So the position of the Flow-through samplers is known in two directions (X-Y) exactly, and in the vertical dimension (Z) only qualitatively.

6.2.1 Position samplers related to the overflow current

The Front and Aft samplers appeared to be orientated parallel to the overflow current. The orientation of the Side sampler towards the stream lines varied during the overflow period. Often the current approached the Side sampler at an angle (β) which varied approximately between 5 and 15 degrees. Consequently most of the Side samples were not taken in an iso-kinetic way. The impact of the sampler orientation towards the current was researched by van Rijn and Schaafsma [Van Rijn & Schaafma 1986]. From the measurements performed during that particular research it was concluded that the dry matter captured by the samplers decreases when the flow approaches the sampler at an angle instead of a parallel current approach.

6.3 Position of the Bottle sampler

The exact position of the Bottle sampler during sampling is not known. The bottle was lowered down in one of the quadrants of the overflow (Figure 6-1). When the sampler reached the surface of the overflow mixture, the records show that immediately the current took control over the position of the Bottle sampler. It appeared most of the time that the sampling depth was about the size of the sampler itself (about 30 cm). The opening time of the sampler for the intake of the overflow mixture cannot be extracted from the video records.



Figure 6-1, the quadrant the Bottle sampler was positioned

6.4 Behaviour samplers when dredging different soils

The different soil types sucked up by the suction pipes influence the current regime at the overflow. Dredging sand, a turbulent current regime is shown (Figure 6-2). The video records show a relatively transparent upper layer, which indicates lower concentrations at this level.

A less turbulent current regime is shown during the discharge of silt or mud. The mixture looks like mayonnaise, which is flowing smoothly over the overflow. It appeared the solids are more homogeneously distributed.



Figure 6-2, the Flow-through sampler is pulled back up the guide ropes.

Although the silt mixture discharged by the overflow appeared to be more homogeneous, on the surface of this mixture also a thin layer of less dense mixture is shown. This layer is probably caused by water in the hopper before the dredging process was started.

6.5 Conclusions on the video monitoring analysis

1. The general sampling procedures are well recorded.
2. Although some video records of the overflow sampling were made, they were not continuous and a time stamp was missing; therefore it is not possible to compare the data from the samplers with the specific current regime (paragraph 6.1).
3. It is shown by the video records that the orientation of the side sampler is not parallel to the overflow current. Also variation of this angle of approach during the overflow process is shown. Together with the aspect ratio of the samplers itself (paragraph 3.2.2) results that sampling by Flow through samplers is not really iso-kinetic.

6.6 Recommendations on the video monitoring

1. The camera on the Cygnus was positioned on a fixed point on the vessel. The crew should take care not to stand in front of the camera, it appeared a several times the camera was recording personnel instead of the sediment plumes.
2. The camera operators should assure the "campaign clock" is activated on the records (don't forget to calibrate the time).
3. The sampling crew for the next measurement campaign should definitely view these tapes before the campaign.
4. At the overflow, the sampling techniques, and the installation of the four samplers was recorded. During the next field trip, a fixed came positioned above the overflow is recommended. The camera should display a continuous time registration on the records. The camera position should be selected to avoid personnel standing in front.

5. If in the next field trial again three-Flow-through samplers will be used, it is recommended to paint the Flow through samplers in different colours, this makes it easier to identifying the samplers on screen.
6. The streamlines at the overflow should be recorded by the fixed camera at the vessels hopper. Extra lights sources shining over the overflow area will improve the quality of the records.

7 Calibration procedures and reliability

7.1 Introduction

For reliable data analysis it is essential to have properly calibrated datasets. Therefore appropriate procedures and sensors measuring reliable data are essential. In this chapter the calibration procedures followed during the measuring campaign will be investigated.

Firstly, the logging procedure of each computer will be described. Secondly, we will focus on the calibration procedures on board the vessel. Because no campaign calibration protocol was available it was difficult to find out exactly what procedures were followed, although an attempt is made to clarify all calibrations performed during the field trial. Subsequently the data will be recalibrated and evaluated as to its reliability for further research use.

7.2 The storage and processing of data

Throughout the field trial in June 2002, two computers logged the characteristic data, from which the physical processes can be extracted. These were the computer of the contractor, Boskalis Westminster NV., and the computer system of North Sea Directorate (the so-called TDS-system). Both contractor and North Sea Directorate computers logged the characteristic data approximately simultaneously, but by different means. Fourteen tracks were sampled during the field trial. Using two computers, 28 datasets are obtained.

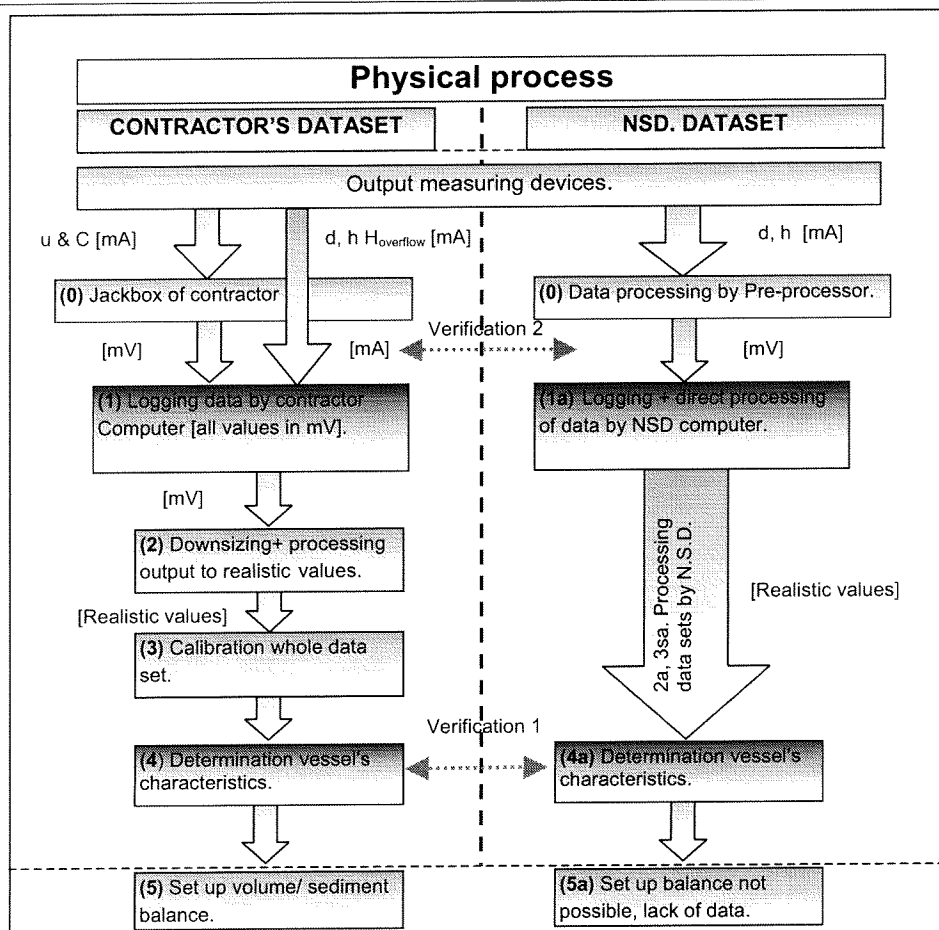
Table 7-1 shows an overview of the data logged by these two computers. The contractor's data set covers all the information needed for the complete set up of a volume or sediment balance. Even the vessel's characteristics during dredging can be extracted from this data file. Although the data set of the North Sea Directorate is valuable as well. For instance the North Sea Directorate dataset can be used to verify whether the dataset of the contractor logged identical data.

Data set	Velocities	Concentrations	Draughts	Levels hopper
Basic data set contractor, mV and mA values (Boskalis).	Incoming by suction pipes	Incoming by suction pipes	Yes	Yes
Dataset North Sea Directorate, physical values	No	No	Yes	Yes

Table 7-1, data used during analyses.

In the next paragraphs the data processing on board of the Cornelia is reviewed. As earlier stated the data was logged by different means. In Figure 7-1 all the procedures are summarised, to support the explanations by text. By reading this figure one should notice that the datasets initially submitted by the contractor contains milli-Voltages only (indicated by (1)).

The dataset submitted by North Sea Directorate was already transformed into physical values (indicated by (4a)). The transformations of the contractor data to realistic values will be performed during this research.



Symbols:

- u Velocity mixture suction pipe.
- C Concentration mixture suction pipe.
- d Vessel's draughts.
- h Hopper levels.
- H_{overflow} Level of overflow

Figure 7-1, processing data by contractor and North Sea Directorate.

7.2.1 Data processing based on the contractor's data (1)

The Jackbox used by Boskalis receives the input from the velocity and density sensors in milli-Amperes. The Jackbox converts these milli-Amperes to milli-Voltages ($V=R \times I$). Besides the density and velocity values also the vessel's draughts and hopper levels were stored into the same datafile (in milli-Amperes). These values were directly extracted from the sensors itself (by clip connections).

With a sampling rate of 0,6 seconds a two-hour dredging sequence produces a log file of approximately 17 columns (17 measuring devices were used) by 12,000 rows. This file was submitted by the contractor to the writer of this report.

A matrix of this size is not easy to handle and data processing with such files costs significant computer time; moreover this level of accuracy does not add any value to this analysis. Therefore the writer of this thesis report decided to reduce the size of the dataset using a custom-made Excel-tool. This tool averaged the values of 8 rows into one row. Eight rows correspond to a sampling rate of 4.8 seconds, which is almost equal to the sampling rate of 5 seconds, which the North Sea Directorate TDS-software is logging. In Figure 7-1, this data set is indicated number (2).

As implied before, downsizing the data file causes errors. These errors are quantified as the results of a sensitivity check in appendix 7.4. The mathematical foundations which support this check are also described in this appendix. In brief one can conclude that because of the small variations between every log, no significant errors appear.

For the understanding of the whole process it is worth noticing that after activating the logging-computer at a specific point of time, immediately all data are stored in the contractor's database. All these data are labelled with the computer time of the contractor. This is in contrast to the logging procedures the North Sea Directorate computer is using.

7.2.2 Data processing performed by North Sea Directorate computer (1a)

As opposed to the computer of the contractor, which gets data from the Jackbox and directly from draught and level sensors, the North Sea Directorate (NSD) computer receives its data from the pre-processor. The pre-processor converts the milli-Amperes to milli-Voltages. Moreover some linear scaling rules are applied during this conversion. Switching on the log of the TDS system, the pre-processor starts logging at a specific point of time, which is a multiple of five seconds. The pre-processor passes on the milli-Voltages to the computer of NSD with a sampling rate of 0.5 seconds.

However, this computer only logs every 5 seconds, by logging the average values of these 10 ($5/0.5 = 10$) values. These signals are stored in one file (indicated in the Figure 7-1 with red with the number 1a). Also the North Sea Directorate computer labels the data with the point of time, related to the clock of this machine.

At this stage, two datasets have been obtained that already have significant differences. Specific data does not have exactly the same time labels and both data sets are logged at a different sampling rate. Moreover the Jackbox and Pre-processor do not make use of the same hardware. Consequently in converting milli-Amperes to milli-Voltages variations may be obtained. Nevertheless theoretically these variations should be linear.

7.3 Calibration on board

Only the contractor's dataset was calibrated during the measuring campaign. The North Sea Directorate's computer had already been calibrated at an earlier stage.

Consequently, in this chapter only the calibration procedure of the contractor's TDS system will be discussed (the left side of the process diagram, Figure 7-1). A specialist of the Boskalis Dredging Development Department (DDD) was responsible for the calibration procedure. Not all calibration-numbers obtained during the calibration were saved, so that it was difficult to simulate the calibration procedures after the field trial. Interviews with the involved parties helped to obtain an insight into these procedure followed during the field trial. Besides these interviews, the TDS-system Users Manual was valuable for getting a better understanding of these processes. During this research first the calibration of depth gauges and level sounders in the hopper is described; second we will go into the calibration procedure of the velocity and concentrations sensors.

7.3.1 Scaling of the depth gauges and level indicators (transducers)

The milli-Voltages from the Jackbox are converted to physicals units (e.g. centimetres or m/s) by using simple scaling equations. The conversion equations depend on the measuring device. The equations for every device are stated in Appendix 7.1 and 7.2).

The principle behind the equations stated in appendix 7.1 is based on the following reasoning. For the depth gauges and level transducers in the hopper, the ranges and the corresponding maximum and minimum values are known. Since there is a linear relation between these values one can obtain the following calculation.

1. Power-range of measuring device:

Minimum value = 4 milli-Volts, corresponds with 0 m

Maximum value = 20 milli-Volts corresponds with 10 m

2. Calculating real values:

Real value [m] = (Measured value – 4) • (10-0) / (20-4)

The contractor performs these scaling for every measuring device. To be sure that the level sounders and depth gauges are making use of the same level of reference, the reading of both devices should be compared while the hopper doors are opened. During this test the inside water level should be the same as the outside level. This test was not performed while calibrating the contractor's TDS system. The reason for not undertaking this check was because the North Sea Directorate system was calibrated a few days before the campaign; during this calibration check both levels were verified.

7.3.2 Calibration of the density and velocity meters

Because calibration of both velocity and density meters is only possible while the pumps are running, these device are more laborious to calibrate. During this calibration procedure, only water was pumped into the hopper. This check is summarised in the next sequence:

The volume before start pumping is determined: $t = t_0$ [s]

$V = V_0$ [m³].

1. On $t = t_0$ the pumps starts and water will be discharged into the hopper with a discharge rate of Q_1 [m³/s], and a corresponding velocity of u_1 .
2. On $t = t_1$ the corresponding volume is equal to V_1 now the pumps will be switched off for a few minutes.

3. On $t = t_2$ again the pumps are switched on with a discharge rate of Q_2 . Again with a corresponding velocity of u_2
4. On $t = t_3$ the pump will again be switched of and the volume V_2 will be determined.

With the information obtained from the sequence stated above the next calibration line can be obtained. In this line u_{measured} is linearly related to u_{real} ; with this relationship all values between these points can be obtained (see Figure 7-2). The steepness and offset are of course the most important numbers in this line.

First run:	$u_{\text{real},1} = \frac{V_1 - V_0}{t_1 - t_0}$	$u_{\text{measured}} = u_1$	Equation 7-1, calibration first run.
Second run:	$u_{\text{real},2} = \frac{V_2 - V_1}{t_2 - t_1}$	$u_{\text{measured}} = u_2$	Equation 7-2, calibration second run.

Now the a/b values and the C (offset) values are known (Figure 7-2), we can determine all the real velocity values. These calibration characteristics from the direct calibration campaign are not available any more. Since the data shows up variations in these values the datasets had to be recalibrated. These recalibrations will be discussed in the next paragraph. Step 3 was introduced to determine the leakage by the hopper's doors. One should notice the leakage is determined while pumping water instead of a sediment mixture into the hopper. Consequently the leakage by the hopper doors can be different during dredging sediment because of the "sealing effect" of the sediment. In early calibration equations this leakage was taken into account. In a later stage of the research this part of the calibration equation was deleted because this factor is suspected of generating unrealistic values.

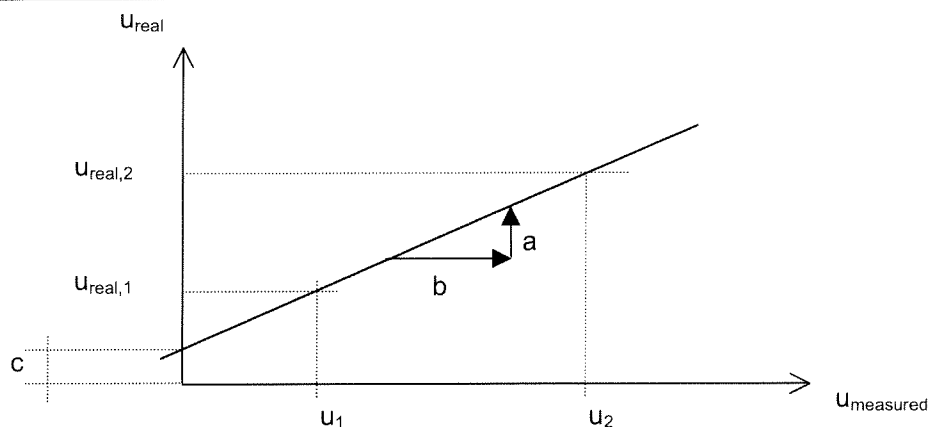


Figure 7-2, Calibration of velocity meter.

The calibration procedure of the density meters is almost identical to the calibration of the velocity meters. Instead of the velocities and volumes in the hopper, the incoming

densities and the vessel's displacements are used: ($C_{i,x}$ [tonnes/s] = A_{pipe} [m²] • u_x [m/s] • c_x [tonnes/m³] .

The results of these on board calibrations and scaling are presented in Appendix 7.2. For each velocity and density meter an equation is present, which shows us how to compute the measured values from the milli-Voltages. For the draught and level sensors the scaling equations are easy to understand, however the calibration equations of the velocity and density meters need more attention. The additional adjustments on the velocity and density meters are made to bring the leakage by the hopper doors into account. Figure 7.1 of appendix 7.1, illustrates these adjustments compared to the original values, hereby for both suction pipes adjustments are made. In paragraph 7.4.2, these adjustments will be evaluated on their reliability. It should be noted that when calibrating the density meter it is implicit that the velocity meter is calibrated simultaneously.

7.3.2.1 Calibration of the overflow level

After consulting DDD, it appeared that the level sounder of the overflow was not calibrated during the measuring campaign. An attempt is made to recalibrate the overflow levels, however because of the initial scaling problems concerning the TDS data sets, this attempt did not succeed. The overflow levels as stated in the appendices should therefore interpreted qualitatively only.

7.4 Recalibration of data

As stated earlier, irregularities were found in the calibration during the set up of the volume balance. In fact the increase of hopper volumes and displacement do not correspond with the discharge of volumes and tonnes by the suction pipes. Figure 7-7, shows the volume balance based on these original values. It clearly shows that the incoming volumes do not correspond with the stored volumes before the overflow is used. Two strategies are chosen to solve these problems, or, at least to get a better understanding of the problems. Thereby the first strategy focuses on the reliability of the data sets; the second strategy focuses on the data sets of the contractor, to establish realistic volume and sediment balance.

The first strategy: matching the two datasets

The data set of North Sea Directorate is said to be very reliable because the payment of the contractors is based on this system, therefore this data set will be used as the point of reference. In ideal situations both sets contain exactly the same data, however we have discovered some differences. The contractor's dataset is quite easy to understand; unfortunately the dataset of North Sea Directorate is hardly accessible, because of the filters and scaling procedures used by the software.

It should be noted that matching both datasets is only performed on the level and draught sensors since no velocity and densities are logged by the North Sea Directorate system.

The second strategy: calibration of contractor's dataset

The second strategy focuses on the contractor's dataset only, in the end of this paragraph we will discover that this recalibration appears to be promising. The velocity and density meters will be calibrated by using the vessel's draughts and hopper levels. The assumption that all the depth gauges and level indicators are calibrated accurately is the basic thought behind this strategy. The assumption can be justified if there is in some respect a match with the first strategy or at least explained why matching these should be (im)possible.

As mentioned before, this dataset also contains the incoming velocities and densities. These values are initially stated in milli-Voltages and milli-Amperes but are translated by the equations of appendix 7.2 to physical values (like m/s or kg/m³). Because these incoming velocities and densities are only logged by the contractor, only these datasets are suitable for the set up of a volume or sediment balance.

In this paragraph both strategies will be reviewed and in the end a strategy will be chosen that will be applied for all 13 trips.

7.4.1 First strategy: matching the two datasets

In matching the two data sets we focus on the data of the front draught sensors logged by both North Sea Directorate and Boskalis computer (Figure 7-1: *verification 1*). The shape of both lines in time appears to be the same; unfortunately an offset is obtained as well. After research it appears that the North Sea Directorate draughts are computed by using a power range of 0-20 milli-Amperes (mA) of the draughts sensors (paragraph

7.3.1) instead of the range 4-20 mA, used for the calibration of the contractors data sets. Figure 7-3 shows the impact of these different scaling ranges applied on one dataset, in the initial phase of the dredging process the draughts differ about 30%. After filling the hopper the differences between both signals decreases to 6%.

Impact of different scaling ranges on vessel's draughts

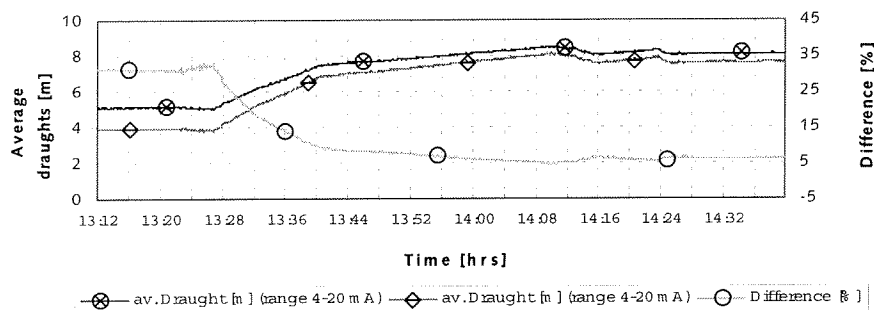


Figure 7-3, draughts computed by using different power ranges.

Figure 7-4 shows the average draughts based on both NSD and Boskalis data set. In this set up the draughts of the Boskalis datasets are also computed by using the power range of 0-20 mA. Both signals appear to be similar, however a time offset is displayed. This offset can be explained by the difference in computer-time of the pre-processor of the North Sea Directorate, which is different from the computer-time of the computer of Boskalis. Consequently identical measured values are stored with a different label of time (Figure 7-5).

Average draughts of NSD and Boskalis compared

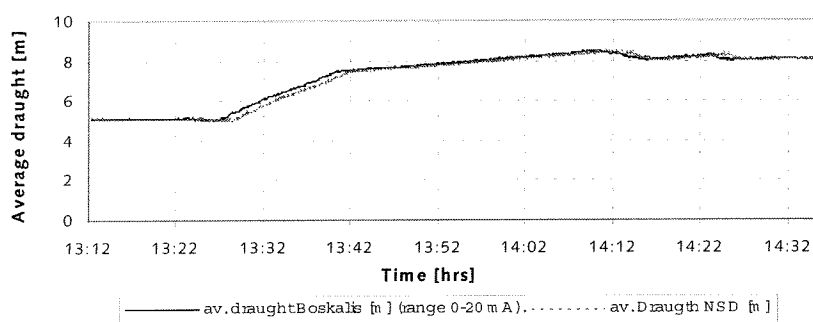


Figure 7-4, average front draught of the vessel, logged by both computers.

The identical shapes of both draught lines in time are quite reassuring. The applied scaling rules do need some more attention. As stated the match is based on a scaling range of the sensors of 0-20 mA. However we already noticed that the data used for the calibration of the velocity and density meters are based on the scaling range of 4-20

mA. Anticipating on the errors found by the set up of the volume and sediment balance (paragraph 7.4.2), the balance was also established by using the characteristic data computed by using the 0-20 mA ranges instead of the 4-20 mA ranges. However the balance results became even worse. Therefore the scaling range of 4-20 mA is retained during this research.

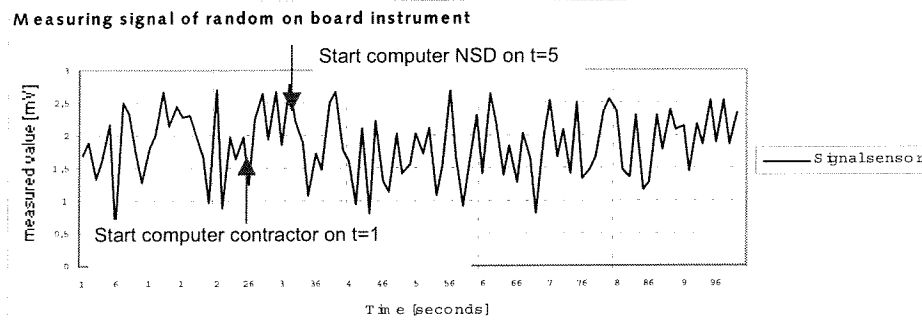


Figure 7-5, matching two datasets, time delay.

Taking the other 6 measuring devices into account should be better for the reliability of this particular research. However because of time restrictions it is decided to focus on these front draughts sensors only. It is assumed that comparing the data obtained by the other 6 devices will lead to the same conclusions.

7.4.1.1 Conclusions on matching datasets of NSD and Boskalis (first strategy)

Whether the contractor's data set is reliable enough for further analyses is the main question to be answered. Therefore two separate logged signals from the front depth gauges are evaluated. From this evaluation (the first strategy) the next conclusions are drawn:

1. The frond-depths during on trip, measured by two draught sensors stored by Boskalis and North Sea Directorate appear to be the same for both datasets the. However the rough data logged by both systems had to be scaled differently. The data of Boskalis was scaled by using power ranges of 0-20 mA instead of the 4-20 mA as prescribed by Boskalis and used by the calibration of the contractors recording system.
2. Only a time offset of about 2 minutes is shown. Together with (1), it is therefore plausible to assume the dataset of Boskalis contained the same data as the dataset of North Sea Directorate. Resulting into the Boskalis dataset being suitable for further research: the set up of the volume and sediment balance.

7.4.2 Second strategy: calibration of the contractor's dataset

As mentioned before this second strategy focuses on the data set of the contractor. Because matching the two datasets of the contractor and North Sea Directorate did work out quite well, recalibrating the data of the contractor's data sets seem to be reasonable (see paragraph 7.4.1).

7.4.2.1 The volume balance

For the calibration of the velocity meters, the velocities in the suction pipes and the increase of hopper volume are used, both obtained from the contractor's dataset. For this calibration we focus on the time before the overflow starts discharging mixture from the hopper. During this period it is assumed that the leakage from hopper doors can be neglected. Taking both assumptions into account the incoming volumes should be the same as the increase of volume in the hopper.

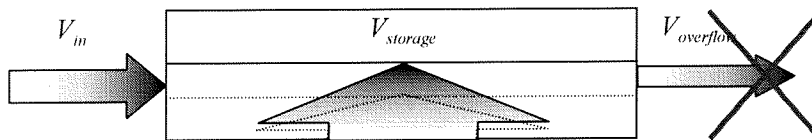


Figure 7-6, the volume balance before start of overflow discharge.

This balance is displayed by Figure 7-6 and described by Equation 7-3. The equation shows that the cumulative incoming volumes per sampling period are equal to the cumulative increase of hopper volume.

$$V_{in} = V_{storage} \quad \longleftrightarrow \quad A_{pipe} \times \sum_{t=0}^{t=T_s} (v_{suction} \times dt) = \sum_{t=0}^{t=T_s} \delta V_{hopper} \quad \text{Equation 7-3, incoming vs. storage volume.}$$

If the system is well calibrated, both volumes ($V_{in} = V_{storage}$) should be the same at the specific period of time before hopper mixture is discharged by the overflow. However it appeared for all 13 tracks that the cumulative volumes discharged by the suction pipes were less than the volumes stored in the vessels hopper (this computation was based on physical values). Of course these outcomes are physically not possible and for this reason adjustments will be made.

Figure 7-7 shows these previous stated findings for a randomly chosen track. The blue line (indicated by **O**) shows the hopper volume (V_{hopper}) during the loading process. The bend in this line indicates the start of using the overflow. The pink line shows the cumulative volumes ($V_{s, cum}$) discharged by both suction pipes (indicated by **Δ**). The red line presents the difference between the two cumulative volumes (**Difference**). Obviously in an ideal situation this differences should be zero.

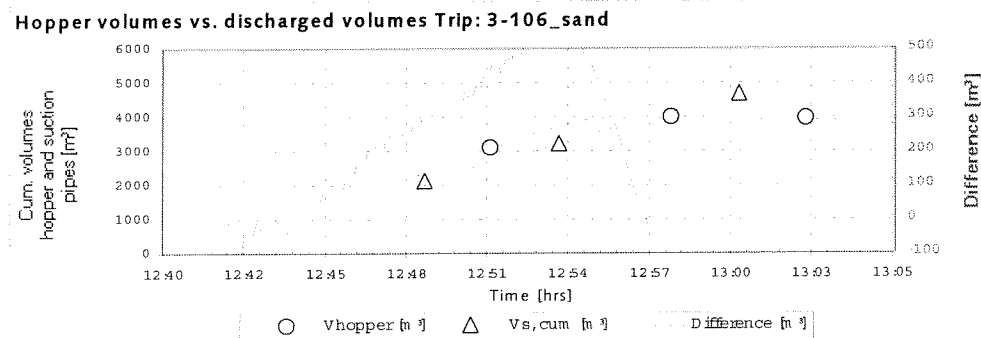


Figure 7-7, cumulative volumes stored and sucked, without corrections

The data set of Figure 7-7 is based on the data logged by the contractor. For the conversion from measuring signals to real values the equations of appendix 7.1 are used. However corrections were made by the contractor for bringing the leakage of the hopper doors into account (appendix 7.2). These corrections were made on the velocity meters and density meters. The corrections on the velocity meters are not taken into account because these corrections appear to show up even poorer results. The corrections on the density meters were retained.

In order to recalibrate the data sets it is decided to adjust the cumulative values measured by the velocity meters in the suction pipes. Instead of the recalibration of the velocity meters the reading of the level sounders could be adjusted, however this signal is considered to be more reliable compared with the measurements by the velocity sensors (paragraph 7.4.1). Therefore no adjustments on these signals are made. Figure 7-8 represents the same track as shown in Figure 7-7, but with adjustments to the incoming velocities.

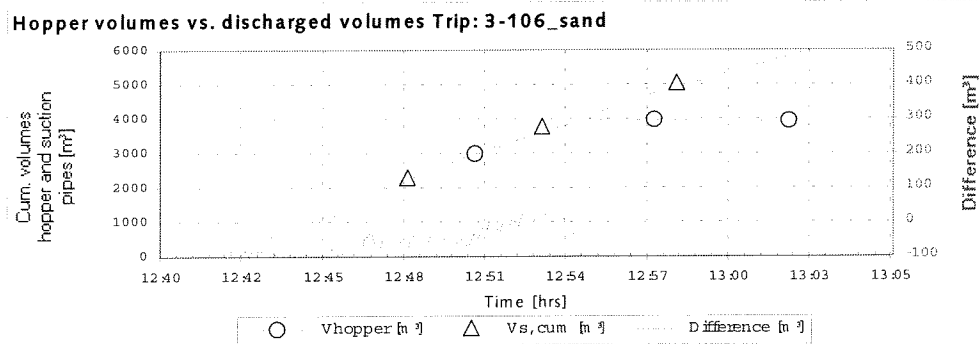


Figure 7-8, cumulative volumes stored and sucked, after recalibration.

The original data shows a constant deficit of about 17% comparing the measured hopper volumes. After adjusting the velocity meters with these specific values, reasonable values are obtained.

Unfortunately for every trip this correction is variable (varying between 14 and 24 % correction). These corrections are displayed for every track in the global input sheet per track. The cause of these variations might be found in the different behaviour of the velocity meters under different soil conditions. Another explanation can be found in the diameter of the pipe where the velocities are measured; during this research the pipe diameter was considered to be 900 mm, identical to the suction pipe diameter. Often smaller diameters than the suction pipe diameter are used at this location .

7.4.2.2 The mass balance

After the velocity meter is calibrated, the density meters can be tuned. This calibration is performed in a similar way to the calibration procedure of the velocity meter because during the calibration of the velocity meters the hopper volumes are used as the reference parameter. For the calibration of the density meters the ships displacements are taken. Again these draught measurements are considered to be the most reliable, therefore the values of the density meters are adjusted during this recalibration. One should notice that the order of calibration is essential because, as shown in the mass balance by

Equation 7-4, the velocities are incorporated. Without reliable velocity values, the calibration is useless.

$$M_m = M_{storage} \longleftrightarrow A_{pipe} \times \sum_{t=0}^{t=t_s} (c_s \times v_s) \times dt = \sum_{t=0}^{t=t_s} \delta M_{displ} \quad \text{Equation 7-4, simple mass balance.}$$

The mass balance is computed by using almost all measuring devices installed on board of the vessel. Consequently the chance that one device breaks down is noteworthy. Therefore when the mass balance appears to be right, it is likely that all measuring sensors on board are well calibrated.

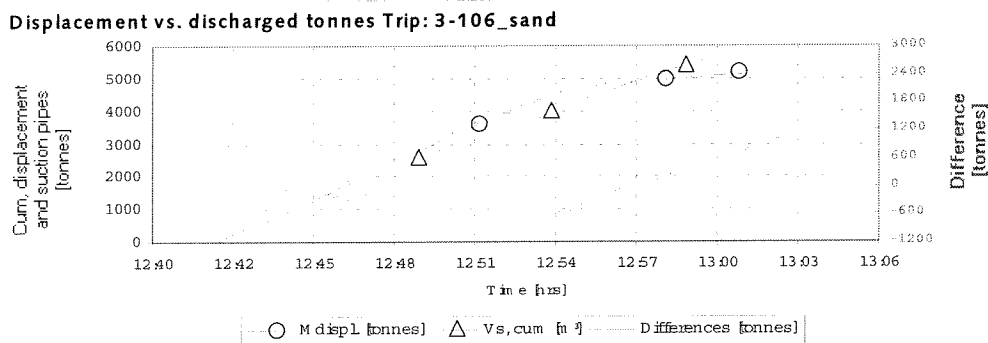


Figure 7-9, cumulative weights stored and discharged, without corrections.

Before any corrections are made on the velocity or density data again a deficit of material discharged by the suction pipes appears (see Figure 7-9).

Surprisingly after the correction of the velocity meter also the mass balance shows quite promising results. During the displayed track 3-106 for example, the cumulative values of the density meter were only manually increased by 1 % (Figure 7-10). Although the adjustments to the density meters were significantly less compared to the adjustments performed on the velocity meters, these adjustments were not the same for all tracks. Reviewing all tracks the maximum adjustments on the density meters were about 4% and the minimum adjustments about -1%.

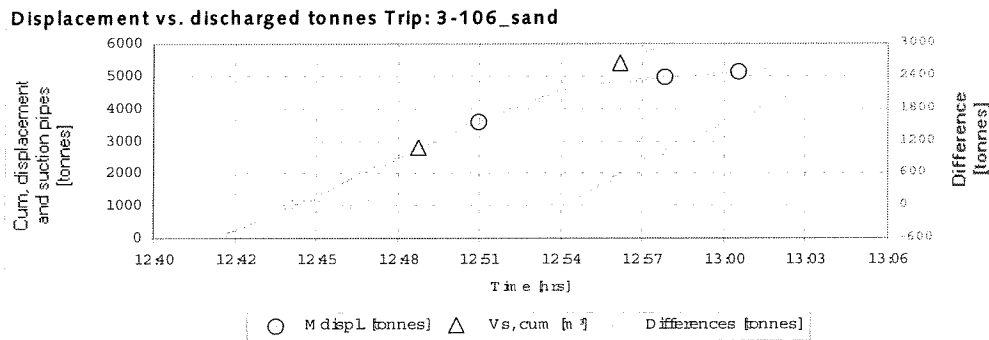


Figure 7-10, cumulative weights stored and discharged, after recalibration.

So far comparisons are drawn between the incoming volumes and the increase of volumes in the hopper extracted from the datasets logged by the contractor. Thereby it is assumed that the draughts are derived by using the power range of 4-20 mA (paragraph 7.4.1). The set up of the mass balance by using the real values of the hopper volumes computed by using the 0-20 mA power ranges resulted in even worse values.

7.4.2.3 Calibration problems

So far, for almost all tracks a proper balance can be obtained by adjusting the velocity and density meter values.

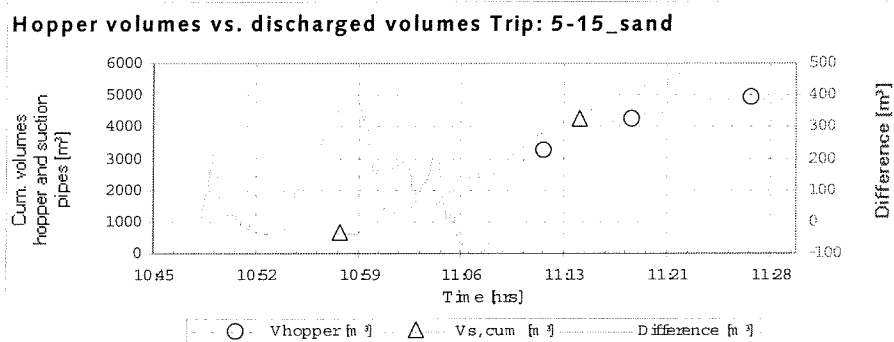


Figure 7-11, example of useless datasets of the set up of a proper balance.

However, for one track the quality of the logged data is questionable. As shown in Figure 7-11 even after recalibration of the velocity meter absolutely no reliable values are displayed. An explanation for these suspicious dataset is found in the adjustments of the suction pipes during manoeuvring the vessel.

When lifting the suction pipes, only water is discharged into the hopper. These fluctuations are probably caused by these significant changes in the consistency of the mixture. Because of the significant variations it is decided not to use this trip for further research.

7.5 Conclusions on recalibration procedures and reliability

From this chapter the following conclusions are drawn:

1. By adjusting original measured values of the velocity meters by 17 to 22% per trip and the measured densities by -1 to 4 %, it is possible to recalibrate the TDS datasets of 13 tracks in the period before the overflow is used (paragraph 7.4.2). One should be careful with this recalibration because it does not automatically mean the entire dredging sequence of the particular trip is calibrated well, because the leaking of the hopper doors is not taken into account while dredging sediment.
2. The data logged during trip 5-15 appears to be useless, this might be caused by the variations of velocities and densities in the suction pipes (caused by turning manoeuvres).
3. The data stored by both North Sea Directorate and Boskalis show up identical values (Figure 7-4). However different scaling transformations are applied.
4. In the set up of the volume and sediment balances it appears that the data logged on board of the Cornelia was calibrated differently (by pumping water only). The sediment at the hopper doors preventing leakage was not taken into account.
5. Because no campaign calibration protocol was available during the calibration of the measuring devices, some calibration figures are not noted properly. Therefore it is not possible to simulate the calibration procedures one year after the field trial.

7.6 Recommendations on recalibration procedures and reliability

During the analysis of the data, some problems appeared. Solving these problems is hampered by the lack of calibration data. By adopting the following suggestions one can avoid or at least reduce these problems in future measuring campaigns.

- Set up and make use of a proper measuring protocol, prescribing full registration of calibration efforts. This should include the items listed below.
- Calibrate the level sounders, depth gauges, velocity meters and density meters.
- Save all used numbers during the calibration on the bridge of the vessel.
- Only use one set of properly calibrated sensors and loggers.
- Check the hopper level sounders manually.
- Check the depth gauges manually.

- Calibrate also the overflow level sensor, and check if the level of the load in the hopper has approximately the same level (no more than 15 to 20 cm difference).
- All calibration values concerning every sensor should be properly stored in one project data base.
- Pinpoint the exact locations of the measuring sensors (velocity and density meters).
- Quantify the effect of the vessels speed on the output of the depth sensors.
- Determine for every soil condition the leakage by the hopper doors.
- Log always which lander is used.
- Check the TDS balance by pumping water only into the hopper.
- Calibrate all measuring sensors separately.

8 The volume and mass balances of the TSHD

8.1 Introduction

Two main components of the overflow release were measured during the field trial in 2002; the Particle Size Distribution and the solids concentration. In this chapter we will focus on measured solids concentrations released by the overflow.

The main objective of these computations is to compare the computed overflow releases with the measured overflow releases (Figure 8-1) during the field trial. Comparing outgoing masses obtained by different means will verify whether the sampling methods used are valuable in characterizing the consistency of the overflow discharge (Chapter 11.2.4).

For the determination of the outgoing sediment fluxes by the TDS-system, sediment balances for 13 sailed tracks have been made. Because both volume and sediment balances are needed for the verification, in this chapter the set up of both balances is discussed. The computed overflow releases are based on the TDS-system data (Figure 8-1), whose reliability is discussed in chapter 7.

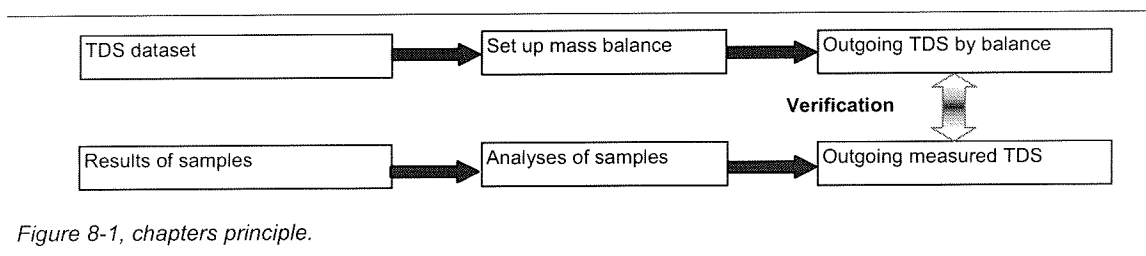


Figure 8-1, chapters principle.

During the set up of these volume and sediment balances problems occur which relate to the reliability of the results of these balances. In this chapter, the cause of these problems will be discussed. Moreover, the sensitivity analyses of the balance set up, increases the understanding of the impact of the different parameters on the results of the balance computations.

8.2 The balance

The idea of a balance is rather simple; the incoming volumes are equal to the storage added to the outgoing volumes. It does not matter what kind of units are used: water, sediment concentrations or Tonnes of Dry Solids (TDS), the basic principles will not change.

In terms of the overflow research, we are particularly interested in the outgoing masses, because these accumulated masses determine the total weights of sediment lost at the end of the dredging sequence.

It is noted that in this balance set-up the leakage through the hopper doors is taken into account while dredging water only (ref. chapter 7.3.4). Besides the leakage, the LMOB³ system was not used during the measuring campaign and therefore it was not necessary to include the system in the set up of these balances.

Figure 8-2 displays the volume balance principles, in the previous chapter we focussed only on the input and hopper volumes. In this chapter, the outgoing volumes are the main interest.

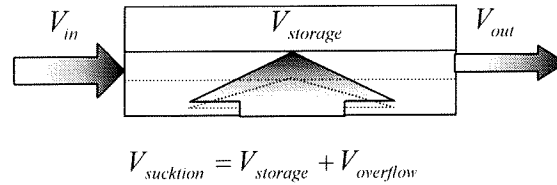


Figure 8-2, the volume balance principle.

8.2.1 The mass balance

The set up of the mass balance is similar to the previously stated volume balance set up. However we are interested in the masses leaving the vessel and therefore the outgoing masses are stated on the left side of the Equation 8-1.

$$M_{overflow} = M_{suction} - M_{hopper} \quad \text{Equation 8-1, mass balance vessel [tonnes].}$$

In dredging terms it is common to express the masses of the balance in tonnes of dry solids (TDS), based on these TDS values we can develop from Equation 8-1 the next TDS balance equation.

$$\frac{d}{dt}TDS_{overflow}(t) = \frac{d}{dt}TDS_{sucked}(t) - \frac{d}{dt}TDS_{hopper}(t) \quad \text{Equation 8-2, the TDS balance for a vessel [tonnes/s].}$$

According to this equation (Equation 8-2), for each particular period of time, the outgoing TDS can be computed from loggings or calculations of TDS_{sucked} and TDS_{hopper}. However, the computed TDS signal in the hopper can be very irregular. In order to smooth this signal the moving average of the signal is used. The τ -value is adjusted until the irregularities are smoothed to an acceptable level. In practice the averaging intervals vary between 30 and 60 seconds.

$$-\frac{d}{dt}TDS_{hopper}(t) = \frac{TDS_{hopper}(t-\tau) - TDS_{hopper}(t+\tau)}{2 \times \tau} \quad \text{Equation 8-3, the moving average of the hopper TDS [tonnes/s].}$$

By further breaking down Balance Equation 8-2, the incoming tonnes of dry solids can be computed with Equation 8-4. The specific densities of the sucked mixture (ρ_s) in this

³ Light Mixture Over Board.

equation are computed by dividing the mass of the load by the corresponding volume of this particular load. Obviously the load is time dependent because of the variation in volumes and densities with time.

$$\frac{d}{dt}TDS_{sucked} = \frac{d}{dt}(C, Q, \rho_l)$$

Equation 8-4, TDS sucked at a specific point of time [tonnes/s].

Having defined the incoming TDS in the suction pipes, it is now necessary to determine the increase in TDS stored in the hopper of the vessel. Equation 8-5 shows the method of computation for this.

$$\frac{d}{dt}TDS_{hopper}(t) = \frac{d}{dt}(C, Q, \rho_s)$$

Equation 8-5, TDS stored in the hopper at a specific point of time [tonnes/s].

The ρ_s , used in Equation 8-4 is replaced by ρ_l . Again this ρ_l is determined by dividing the weight of the mass by the volume of the mass.

The weight of the mass is determined by the increase in displacement, in tonnes of water. The volume of this load can be extracted from the increase of hopper volume.

Although the basic principle of a balance is straightforward, obtaining accurate values turns out to be rather complicated. As described in the previous chapter, the large number of variable quantities and inaccuracies during the calibration of the TDS system are responsible for these problems. Besides the inaccuracies in the data, we also have to deal with errors caused by the computations of the balance. In paragraph 8.6 of this chapter these errors will be evaluated.

8.3 Time ranges of interest

In the set up of the balance not the entire dredging period is taken into account. Because of the problems concerning the accuracy of the results and to structure the set up of the balance we first focus on two periods of interest. The first period starts at start dredging (t_s) and ends at start of overflowing (t_o). The second period of interest starts at t_o and ends at the time the overflow level is adjusted (t_{ess}).

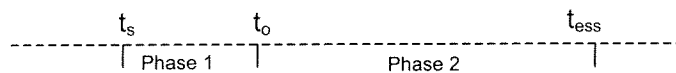


Figure 8-3, definition of time ranges [hrs].

8.3.1 Before start using overflow (phase 1)

When dredging sand, the level of the mixture in the hopper reaches the overflow level within 10 to 15 minutes. During measuring campaign when dredging mud or silt, phase 1 took 15 to 20 minutes or sometimes even longer up to the entire loading time of the

vessel. This is remarkable because usually the overflow period while dredging these types of soils is minimised a few minutes.

As stated in the previous calibration chapter, this first phase is used for the (re)calibration of the velocity and density meters because the increase of the mixture volumes in the hopper should be equal to the volumes discharged from the suction pipes.

8.3.2 Steady state situation (phase 2)

Throughout the analyses of the outgoing masses, we mainly focus on the steady state situation. As stated before, this period starts just after the overflow starts flowing and ends just before the level of the overflow is adjusted. For every trip this period of steady state varies.

During this steady state situation, the volumes discharged at the overflow are considered to be the same as the volumes delivered by the suction pipes (in = out). With this assumption the delay between incoming and outgoing volumes is ignored. Later in this chapter we examine the effects of ignoring this delay.

8.4 Computations

In paragraph 8.2 the basic principle and corresponding equations of the mass balance is explained. In this paragraph we will go into the computation procedures of the mass balance. Throughout this explanation, the dataset of sand trip no.106 is used for reference. Throughout the whole analyses more trips are analysed, making use of the same computation template. The results of these analyses are discussed in paragraph

8.4.1 The inflow

8.4.1.1 Discharged volumes by suction pipes

Each suction pipe is equipped with one velocity meter, positioned just after the suction pumps. The diameter of the suction pipe at this location is 900 mm. Every 4.8 seconds the average velocity for this corresponding period of time is logged into the custom made database (ref. chapter 7.2). This database is used for the computation of the balance.

The velocities in the suction pipes are translated to discharges by Equation 8-6.

$Q_{s1,SB} = A_p \times V_{s1,SB}$	Equation 8-6, discharge of SB suction pipe [m ³ /s].	$Q_{s2} = Q_{s1,SB} + Q_{s1,PS}$	Equation 8-7, discharge of two suction pipes [m ³ /s].
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$A_p = \frac{1}{4} \times \Pi \times D_p^2$	Equation 8-8, determination of pipe area [m ²].	$TDS = C_{vg} \times V_l \times \rho_g$	Equation 8-9, simplified TDS equation [tonnes/s].
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Because we are interested in the total amount of mixture coming into the vessel's hopper, the discharges of both suction pipes are added together to give one incoming discharge (Equation 8-7). Equation 8-9 shows the simplified equation for the computation of the Tonnes of Dry Solids of a certain volume V_l (m³). C_{vg} (%) stands for the volume concentration of the soil particles and ρ_g stands for the specific density of the grains (tonnes/m³). All TDS equations in this chapter are based on this equation.

8.4.1.2 Tonnes of dry solids discharged by suction pipes

Besides the measured velocities in the suction pipes, the wet densities of the upcoming mixture have also been measured (ρ_s). The density sensors use of radioactive radiations which are beamed through the pipe. The sensors are positioned just after the suction pumps. For the set up of the mass balance by dry matter, the wet densities have to be converted to tonnes of dry solids.

Equation 8-10 shows the cumulative TDS calculation for the incoming tonnes of dry solids.

$$TDS_{s2}(t) = \sum_{t=t_s}^{t=t_{\text{end}}} \rho_g (C_{vg1,SB} \times Q_{s1,SB} \times \Delta t + C_{vg1,PS} \times Q_{s1,PS} \times \Delta t) \quad \text{Equation 8-10, the computation of incoming TDS.}$$

$$\Delta t = 4,8s$$

In which: $C_{vg1,SB} = \frac{\rho_{s1,SB} - \rho_w}{\rho_g - \rho_w}$ and $C_{vg1,PS} = \frac{\rho_{s1,PS} - \rho_w}{\rho_g - \rho_w}$

As the incoming TDS's for both suction pipes are not calculated separately, errors in the velocity or density loggings by one or both suction pipes are more difficult to detect. To make sure both pipes worked properly; the measured concentration and velocities signals were checked before the data were used for analyses. During this check the signals are reviewed on instantaneous signal drops (caused by for instance lifting a suction pipe) moreover the signals are compared with overall averages.

8.4.2 The storage

The computation of the tonnes of dry solids, stored in the hopper is almost identical to the previous stated computations of TDS. However the determination of the specific density of the stored load (ρ_l) differs.

Now this specific load is computed by dividing the mass of the stored load (M_l) by the volume (V_l) of the load (Equation 8-11), instead of the using the readings of velocity and concentration meters.

$$TDS_{\text{hopper}}(t) = C_{vg} \times V_{\text{hopper}} \times \rho_g$$

In which: $C_{vg} = \frac{\rho_l - \rho_w}{\rho_g - \rho_w}$ and $\rho_l = \frac{M_l}{V_l}$ Equation 8-11, the computation of incoming TDS.

The mass and volume of the stored mixture are determined by using specific nomograms. For the determination of the hopper volumes the Ullage table is used (appendix 7.5.1), and the vessels displacement is determined by using Carène diagrams (appendix 7.5.2). Since these nomograms are essential for the continuous balance computations the diagrams have been transformed into polynomial equations.

8.4.2.1 The hopper volume

Four level sounders in the hopper monitor the level of the dredged mixture (see Appendix 7.5.1). From these four levels an average hopper level is determined. By

using this level and the Ullage table of the Cornelia, the volumes of mixture stored in the hopper can be determined. Equation 8-12 shows the Ullage tables by numbers. For every average mixture height the hopper volume can be computed.

$$V_{\text{hopper}} = 0.07077h^4 - 4.993h^3 + 78.394h^2 + 206.7h + 7.8$$

Equation 8-12, relations of hopper volumes vs. average levels [m³].

8.4.2.2 The loads weight

For the determination of the weight of the load, the change of displacement of the vessel is used. The displacement of the vessel is obtained from the Carène matrix. In this nomogram the displacement of the vessel is correlated to the draught and trim of the vessel. For the computation of the loads in tonnes, the displacements have to be multiplied by the specific density of the water the ship is sailing in.

In the balance computations performed during this research a specific density of $\rho_{\text{sea}} = 1.02$ tonnes per cubic meter sea water is used.

$$M_{\text{displ.}} = -3,1905d^4 + 69,717d^3 - 525,85d^2 + 3487,5d - 2757,2$$

Equation 8-13, relations of average draughts vs. tonnes of displacement [tonnes].

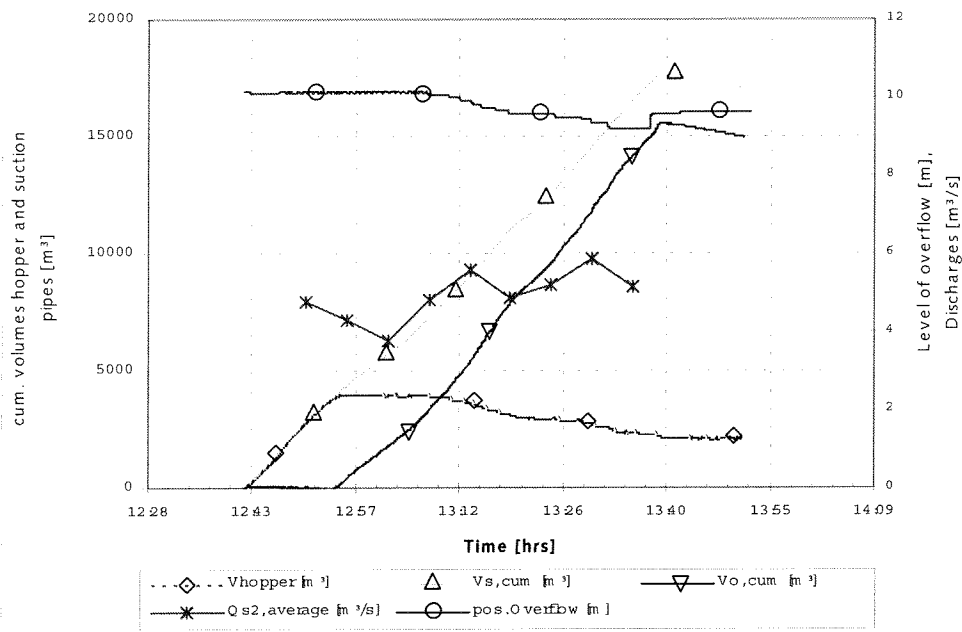
8.4.3 The Outflow

Now that the inflow and storage into the hopper are known, the outflow can be computed. In this paragraph the outflow by three different means will be reviewed, the discharged volumes, masses and tonnes of dry solids. Again sand trip no. 106 is used to support the explanations, for the other 12 tracks one is referred to appendix 9.1 and 9.2.

8.4.3.1 Released volumes

As stated in paragraph 8.2, the overflow release is computed using Equation 8-2. This equation shows that the overflow discharge is constant as long as the level of overflow is not adjusted. In this steady state situation the overflow discharge is considered to be equal to the volume discharged by the suction pipes.

Hopper volumes and discharged volumes Trip: 3-106_sand



Symbols:

V_{hopper}	Volume mixture in hopper.
$Q_{s2, average}$	Average discharge of two suction pipes.
$V_{s, cum}$	Cum. volume sucked by suction.
$V_{o, cum}$	Cum. volume released by overflow.
$pos. Overflow$	Level of overflow funnel.

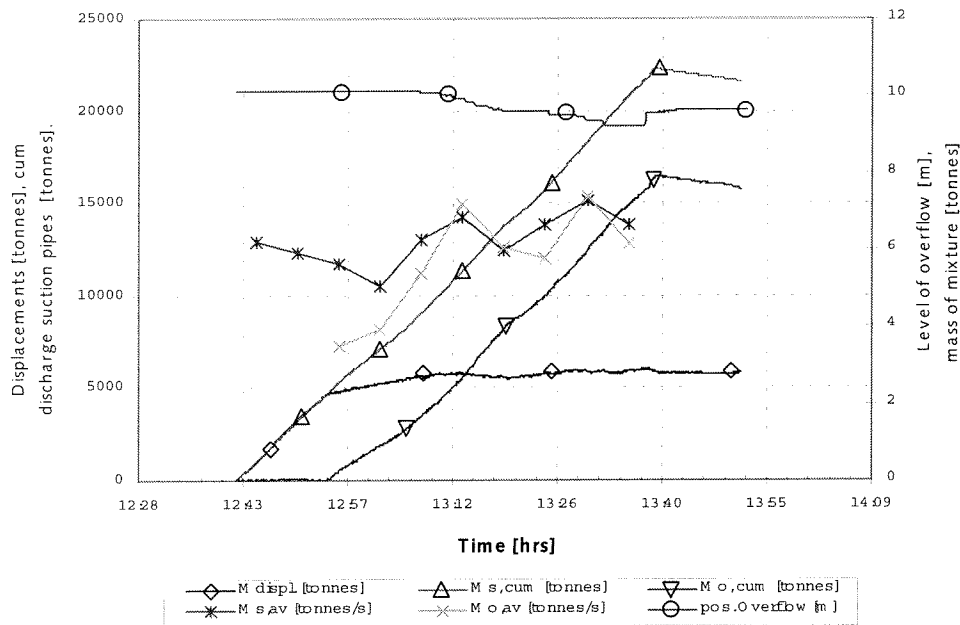
Figure 8-4, the volume balance of sand trip: 3-106.

Figure 8-4, shows the loading sequence of sand, during trip 3-106. In the first phase of the sequence, the incoming volume delivered by the suction pipes ($V_{s,cum}$) is equal to the increase in hopper volume (V_{hopper}). At the start of phase 2 (ref. Figure 8-3), the hopper volume stabilises and the excess mixture flows overboard ($V_{o,cum}$). The cumulative overflow volume is computed by deducting the hopper volume from the cumulative volume sucked by the suction pipes. At the end of the second phase, when the level of the overflow is adjusted to a lower level ($pos. Overflow$), the discharge at the overflow immediately increases (presented by the increase of steepness of the $V_{o,cum}$). After a few minutes a new steady state situation is created where the discharge of the overflow is about equal to the discharge from both suction pipes. The average discharge rate of both suction pipes-combined is displayed by the $Q_{s2,average}$ line. The average values are computed by multiplying the velocities of both suction pipes (averaged over 5 minutes) by the area of the suction pipe.

8.4.3.2 Release of mass

The results of the mass balance computations are illustrated in Figure 8-5. Again the variations in overflow are clearly visible in the results. For instance when lowering the weir, the cumulative mass discharged by the overflow ($M_{o,cum}$) increases. In addition to the cumulative values, the average values of the incoming and outgoing masses are computed at time intervals of 5 minutes. Generally the outgoing masses are smaller than the incoming masses otherwise the vessel will not be loaded. However at 13:12h the outflow masses exceeds the incoming masses. This can be explained by the variation of the level of the weir.

Displacements and discharged masses Trip: 3-106_sand



Symbols:

M displ	Displacement in tonnes.
M s, av	Average mass mixture sucked by suction pipes.
M s, cum	Cum. mass of sucked mixture.
M o, av	Average mass released by overflow
M o, cum	Cum. mass released by overflow
pos. Overflow	Level of overflow funnel.

Figure 8-5, the mass balance of sand trip 3-106.

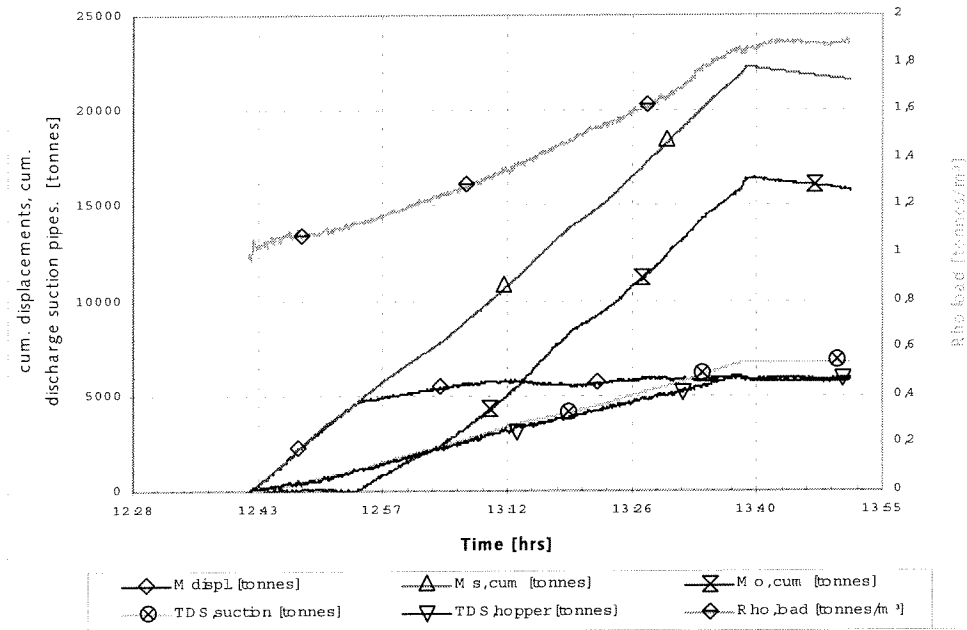
8.4.3.3 Release of Tonnes of Dry Solids

As was seen in the mass balances, the release of TDS by the overflow is not the same as the incoming amount of TDS. Between the discharge into the hopper by the suction pipes and the release by the overflow, a sedimentation process takes place, which results in the storage of TDS in the vessel's hopper.

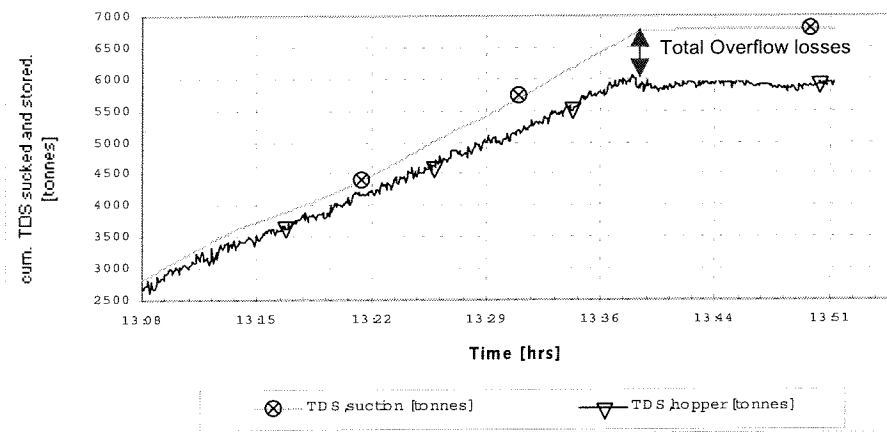
The amounts of TDS released by the overflow at the end of a trip are computed by deducting at the end of the trip the cumulative TDS's sucked ($TDS_{suction}$) from the TDS's

stored in the hopper (TDS_{hopper}). Figure 8-6 shows the TDS balance of sand trip 3-106, the amounts of TDS, released at the end of steady state situation is about 155 tonnes.

TDS balance Trip: 3-106_sand



TDS balance (2) Trip: 3-106_sand



Symbols:

M displ.	Displacement in tonnes.
TDS, suction	Tonnes of dry solids discharge by two suction pipes
Ms, cum	Cum. mass of sucked mixture.
TDS hopper	Tonnes of dry solids stored into hopper
Rho, load	Cum. mass released by overflow
Mo, cum	Cum. mass released by overflow.

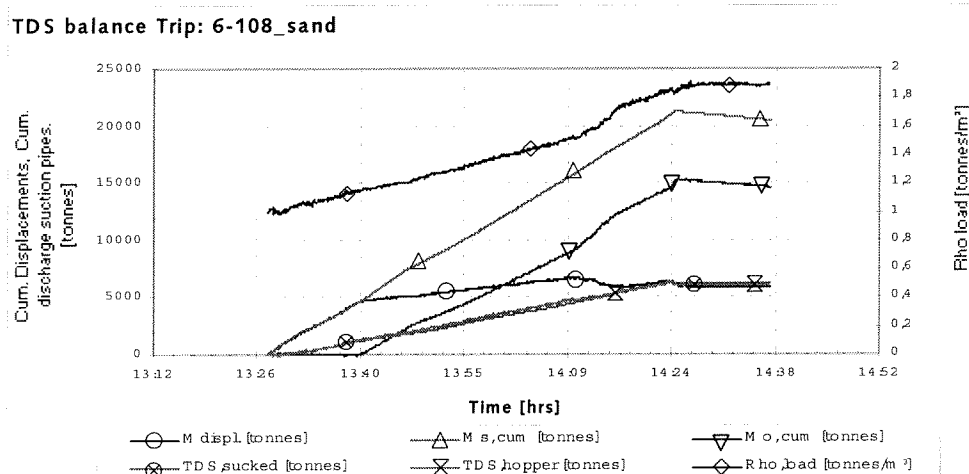
Figure 8-6, The TDS balance of sand trip 3-106.

One should notice, this value is not very accurate because of the fact that the fluctuation of the TDS_{hopper} signal is about the same order magnitude; moreover the data set on which the balance is based seem to be suspicious (chapter 7.4.2.1). More accurate values of the TDS losses can be extracted at the end of the dredging sequence. The second graph of Figure 8-6, shows these total overflow losses.

In Figure 8-7 another example of the TDS balance is displayed (trip 6-108). Although using the same template as used with sand trip 3-106, no overflow losses are computed. This particular result conflicts with the measured values at the overflow. Therefore the set up of the computation will be reviewed more extensively. In the next paragraphs the cause of this specific mismatch will be discussed.

In appendix 9, the volume, mass, and TDS balances are presented for all 13 tracks (the data of trip nr 15 appeared to be useless [ref. chapter 7.4.2.3]). Most of these corresponding TDS graphs clearly show a release of TDS, however it is yet not known if these values are usable for further research.

By reading this appendix one should notice that in some cases in the initial phase of the dredging the specific density of the load (Rho_{load}) is highly variable. These fluctuations are caused by the initial tuning errors.



Symbols:

M displ.	Displacement in tonnes.
TDS, suction	Tonnes of dry solids discharge by two suction pipes
Ms, cum	Cum. mass of sucked mixture.
TDS hopper	Tonnes of dry solids stored into hopper
Rho, load	Cum. mass released by overflow
Mo, cum	Cum. mass released by overflow.

Figure 8-7, TDS balance trip 108, no TDS losses computed.

8.5 Verification

In the previous paragraph it was shown that no TDS losses were computed during sand trip: 6-108. However we know for sure that sediment was released by the overflow. In this paragraph the overflow losses of this particular trip will be estimated by using the measured concentration values. Although the results of these estimations are not very accurate, the order of magnitude can be essential by the interpretation of the results obtained from the sensitivity analysis that is performed in the next chapter.

In chapter 11 the computed and measured values all sand and silt trips are reviewed. The results of all these computations will be investigated to identify specific trends and relationships.

Estimation of overflow losses trip 6-108

During sand *trip 108* (appendix 9.1) a volume of about 15,000 m³ was released by the overflow. Most of this volume consist of process water, however sediment concentrations are measured as well (appendix 9.1). The TDS released by the overflow will be computed for Phase 2 (paragraph 8.3).

The flow-through samplers measured an average concentration of about 60 kg/m³ (see appendix 10.2) during this particular trip. This value corresponds to a volume percentage of grains of 2.4 % (C_{vg}). This, together with an average discharge at the overflow of 5 m³/s in the steady state situation ($Q_{s2,average} = Q_{overflow}$) provides an estimated 0.33 TDS per second discharged by the overflow. The total overflow time in the steady state period was approximately 30 minutes; with a cumulative discharge of 585 TDS.

As stated in the output sheet in appendix 9.1, the two suction pipes discharged about 15,000 tonnes of dry solids. Consequently 4 % of the sucked TDS is discharged by the overflow (= overflow losses). Of course the reasoning is very rough and the local variations are not taken into account. Nevertheless the amounts of TDS release by the overflow are relatively small comparing to the amounts of TDS discharged by the suction pipes. Our main interest is whether the accuracy of the computed balance is sufficient to come to a reliable verification of the measurements. This question will be reviewed in the next paragraph.

8.6 Sensitivity analyses

As stated in the verification paragraph, the outgoing TDS as determined by the TDS balance is almost zero. Nevertheless TDS losses are measured. This discrepancy is caused by the processing, measuring and computational operations. In this paragraph these sources of errors and the effect of these errors on the computations will be reviewed.

8.6.1 Sources of errors

Several parameters are used in the computation of the overflow releases of TDS. All these parameters vary; moreover these variations have a stochastic distribution.

The recorded weight of the load varies due to variations in the accuracy of the pressure sensors and Carène diagram. The variations in the recorded volume of the load may occur due to the inaccuracy of the acoustic sensors and the use of the Ullage table. Variations in water density may occur due to the presence of fresh water or be caused by tidal currents along the coastline.

8.6.1.1 Draughts sensors and densities

The hopper pressure measuring method is fully automated. Both densities of water and sand grains are considered to be constant in the calculation procedure of TDS. Errors will occur if either or both of these densities are not accurately measured.

The density of the surrounding water is not constant. Variations with space and time occur (sometimes caused by tidal influences). Also, the density of dredged material varies, however during the field trial, the specific densities of the sucked sand should be considered to be constant.

The level of the load is established by using two level sounders and an accuracy of 0.5 percent across the calibrated span may be assumed. This value is obtained from the manuals of the measuring sensors.

In the next table the errors caused by specific parameters and measuring devices are listed. These percentages will be used in the sensitivity analyses.

	Errors in density measurements	Percentage error.
a.	Error in density of water	0.2 %
b.	Error in specific density of dredged material (ρ_s)	1.5 %
c.	Error in pressure measurement	0.5 %
d.	Error in level sounders	0.5 %

Table 8-1, errors caused by density measurements ⁴

8.6.1.2 Data processing

As stated in the in the calibration paragraph, some averaging operations are applied to the logged data sets, to reduce the size of the data sets. Averaging data causes errors. However, the fluctuation in values on this time scale is so small that negligible errors occur from this operation. In appendix 7.4 this particular operation is reviewed.

8.6.1.3 Computations

Small numbers resulting from operations with large numbers, cause relatively large errors. For example the computation of the specific density of the load in the first phase of dredging is very sensitive to small variations. In this phase the displacement of the vessel is relatively large compared to the volume of the hopper load.

8.6.1.4 Errors in using Carène diagram and Ullage table

Carène diagram.

As stated before, the Carène diagram gives the relationship between the draft and the displacement of the vessel. The weight of the vessel is established by multiplying the displacement by the surrounding water density. Because the density of the surrounding

⁴ Extracted from the graduation thesis of R. Rullens. "The TDS system", NSD library.

water may differ, the displacement of the vessel differs and thus the draft of the vessel. The consumption of consumables such as fuel and water will be discussed later in this chapter. If the density of the surrounding water differs from that used in the relation between draft and weight, a systematic error of up to 2 % of the weight of the vessel may occur (densities vary from 1.00 tonnes/m³ to 1.02 tonnes/m³).

In the analyses, the Carène diagram was transformed to a polynomial. This polynomial approximates the Carène diagram rather well, with an error of 5 to 20 m³ displacement. Since the dependency of trim is not taken into account with the set up of the polynomial, the trim causes errors of 20 to 40 m³ in displacement. Particularly in the first phase of the loading process these errors may occur because, in this phase, the vessel is trimmed to the maximum.

Also, the bending of the vessels hull is not taken into account. Between the pressure sensors, located fore and aft in the ship, the vessel sags, actually causing more displacement than that measured.

Ullage table

The Ullage table give the relationship between the level of the load in the hopper and the hopper volume. Fewer errors are expected from the computations with the Ullage table compared to the use of the Carène diagrams. The accuracy of the Ullage table is affected by the vessels trim as well, because the inner shape of the hopper is not totally rectangular. Moreover the construction of the hopper doors affects the accuracy in the initial phase of loading. However, when the hopper is filled both sources of errors will be averaged down and more accurate values are obtained.

8.6.1.5 Errors caused by the leakage of the hopper doors.

In the set up of the balance, the leakage by the hopper doors is initially taken into account. However after the overflow starts' discharging it is not known how this leakage develops with time. A decrease of the leakage seems to be the most appropriate hypotheses because of the increase of the relative density of the hopper mixture material. This process results in the increase of the interlocking of the grains, resulting in less grain losses through the hoppers doors. In the set up of the balances the change of leakage is not considered to be significant and is therefore neglected.

8.6.1.6 Errors cause by the use of fuel during one dredging sequence

During a dredging sequence fuel is used by the installed power packs. A rule of thumb tells that for every installed horsepower, about 0.19 kg (or 0.225 l) of fuel is used per hour.

The total installed diesel capacity on board of the Cornelia is about 7805 kW, which is about equal to 10,619 hp. Consequently during every hour 2 tonnes of diesel is used. During dredging sand or mud, these amounts can be neglected.

The discharge of water used by all processes except the dredging process is considered to be zero.

8.6.1.8 Errors by measuring devices

The density and velocity meters are not located at exactly the same position. Consequently the measured density does not correspond exactly with the measured velocity. However the variations on this time scale (less than 1 second) are very small and therefore this error is neglected in the analyses.

The density meter of the incoming mixture makes use of radioactive radiation. The thickness of the pipe wall is an important parameter in the calibration of this device. The pipe wall is under erosive attack by the mixture, which is discharged by the pipes. Again the timescale of these fluctuations is small compared to the duration between two calibration procedures. Therefore this source of error is neglected as well.

8.6.2 Sensitivity of the balance model.

A sensitivity analyses is performed on the balance computation sheet. In this analysis the effects of the balance parameters on the computed values is shown. For the definitions of the time periods one is referred to Figure 8-3.

In Table 8-2 and Table 8-3, the effects of adjustments of the parameters on the volume concentrations of the grains and the tonnes of dry solids are displayed. Both, the new obtained values and the percentage of change are shown. More detailed information is available in appendix 8.

Table 8-2 shows the effects of these adjustments on the computed TDS values, discharged by the suction pipes.

Parameter	Adjustment [%]	TDS on $t_{0,abs}$ [tonnes]	TDS on t_0 [%]	TDS on $t_{ess,abs}$ [tonnes]	TDS on t_{ess} [%]
ρ_w	2	1051	-9.8	1149	-8.7
ρ_g	2	1152	-1.2	1242	-1.2
Velocity meter	2	1189	2.0	4502	2.0
Density meter	2	1317	13.0	4918	12.5

Table 8-2, sensitivity analyses, upcoming mixture

Table 8-3 shows the effects on the values computed by using the displacements and hopper volumes.

Parameter	Adjustment [%]	TDS on $t_{0,abs}$ [tonnes]	TDS on t_0 [%]	TDS on $t_{ess,abs}$ [tonnes]	TDS on t_{ess} [%]
ρ_w	2	1149	-8.66	4554	-1.4
ρ_g	2	1242	-1.21	4562	-1.2
Draught at t_s	2	977	-22.3	4338	-6.1
Draught at t_0	2	1716	36.4	-	-
Draught at t_{ess}	2	-	-	5117	10.8
Level at t_s	2	1096	-12.9	4456	-3.5
Level at t_0	2	1291	2.6	-	-
Level at t_{ess}	2	-	-	4653	0.8

Table 8-3, sensitivity analyses, by hopper level and draughts

The sensitivity of the balance to the specific density of the surrounding water is remarkable. In the course of the dredging sequence, as the hopper fills up with the sand the sensitivity to this parameter decreases.

The measuring errors concerning the level sounders and draught sensors cause tremendous variations in the TDS output. However in the course of the dredging sequence these variations are become also less.

This particular decrease of variation can be explained because in the initial phase of the dredging the displacement [in tonnes] of the vessel is much more than the weight of the stored mixture in the hopper. Using these numbers in the TDS computations causes significant variations in the output.

8.7 Conclusions on the volume and mass balances

From this chapter the next conclusions can be drawn:

1. The quantitative validation of the overflow samplers by comparing the measured concentrations with the TDS balance computed concentrations is not possible.
2. During the sensitivity analyses it appeared that variations in the input data of the balance causes errors, which were greater than the measured TDS values at the overflow. Moreover during two sand trips, no overflow losses were computed at all, while losses were measured by the overflow samples. Such results make the results of the balance computations doubtful.
3. In the set up of the balance of the TSHD three levels can be distinguished.
 - a. The first, easiest balance is the volume balance, for the set up of this balance the incoming and stored volumes are used.
 - b. The second level, the set up of the mass balance, the incoming volumes and densities have to be known, together with the variations in displacement, the mass balance can be established.
 - c. The third level is the set up of TDS balance, this balance makes use of all parameters stated before but additional computations are performed, both aspects makes the output very sensitive to small variations of the input parameters.
4. The density of the surrounding water and the values measured by the density meters in the suction pipes have a significant influence on the results of the TDS balance. During the next field trials these parameters should be monitored extensively.
5. A delay exists between the measurement of physical variations and the actual physical variations. These variations cause instantaneous errors in the TDS output of TDS balance.
6. The use of fuel by the vessel during one dredging sequence does not have a significant influence on the output of the TDS balance.
7. Because of the few parameters involved in establishing the volume balance, the results obtained from the volume balance are considered to be reliable. Consequently for all of the trips during the steady state situations the incoming volumes can be considered equal to the outgoing volumes.

9 Overflow samples analysed

In the June 2002 field trial, the overflow was sampled during 14 trips. Because of initial budget constraints the full analysis by TNO-NITG of all 14 tracks was not possible. Instead, a stepwise approach was adopted. Initially all samples from 2 tracks were analysed but no trends or physical causes were found that could explain the obtained results. Therefore, it was decided to order the analysis of an additional 4 tracks at the TNO-NITG laboratory. The results of these additional 4 tracks were in some aspects more promising, because during some tracks the data showed up some trends. However clear physical explanations for the obtained data were still missing. Moreover, the statistical analyses indicated that more data was favourable for the reliability of the results. Taking all these aspects into account, it was decided to order the testing of the samples from the remaining 8 tracks.

In this chapter the results of the analysis of the overflow samples will be reviewed. The focus will be on the dry matter contents (concentrations) and Particle Size Distributions. To structure this process, the results are divided into 2 groups and each group will be reviewed separately:

- **Dredging in sand soils (1)**
 - Concentrations [kg/m^3]
 - Particle Size Distribution [-]
- **Dredging in silt/mud-mixed soils (2)**
 - Concentrations [kg/m^3]
 - Particle Size Distribution [-]

Within each group the results will be first reviewed in the steady state period of the overflow process. After that, the results of the entire overflow period will be analysed. To break down all information the standard questions are applied. These questions are different for the sand and silt trips and are written down in tables, the answers to these questions will be written down into tables as well.

It is noted that the interpretation of the test results is a subjective way of analysis because the writer performs both the reading and the interpretation of the results itself. Hypothetically for this problem a solution can be found by setting up a list of conditions that can be used to answer the characteristic questions. However the stochastic character of the results of the samples makes this approach unrealistic. These findings will be confirmed in the next chapter 10, the Statistical Analyses.

9.1 The corresponding appendix no. 9

The corresponding appendix of this chapter is essential for a better understanding of the analyses. Appendix 9 contains the results of overflow samples and balance computations per track. For each track two pages are presented. The first page shows the measured data, the second page shows the computed data.

On the first page of each track 4 graphs of measured overflow results are shown. The graph on top shows the d_{10} values of the different samples plotted against time. The 2nd graphs shows the d_{50} values against time and the 3rd graph, shows the uniformity coefficient (d_{60}/d_{10}). The uniformity coefficient is a measure of the degree of homogeneity in the distribution of particle sizes. In natural conditions, the d_{60}/d_{10} values are about 2 to 5 [ref. -]. When dredging sand no natural condition is present at the overflow, therefore much larger numbers are displayed. Dredging silt results in significantly more homogeneous overflow samples.

The 4th graph shows the solids concentrations of the samples. These values are computed by multiplying the dry matter of particles [g/g] with the density of the process water [$\rho = 1020 \text{ kg/m}^3$].

By reading the sample graphs, one should bear in mind that no linear relation between the data points exists, although this is suggested by the straight lines drawn in-between the sampling points. The connecting lines are only displayed for presentation purposes. Besides the selection of the overflow samples results, two TDS process graphs are plotted. In these graphs the position of the overflow, the incoming densities and velocities, the draught of the vessel and hopper levels are displayed against time. It is noted that two y-axes with different scales are used.

For all trips the vessel is trimmed backwards in the initial phase of the dredging process, however during the filling the hopper the vessels trim is reduced to almost zero.

The second page of each track shows the results of the TDS computations. 3 graphs are displayed for each track. The first graph shows the results obtained from the volume balance, the second graph shows the results of the mass balance and the third graph show the results of the TDS balance. It should be noted that the reliability of the results is in some aspects questionable (ref. chapter 8.5), however as conclude in this chapter the discharge computations of the overflow seems to be quite accurate.

Finally, it is noted that for all sampling points and their corresponding TDS graphs Greenwich Mean Time is used.

9.2 Dredging sand

In this paragraph we elaborate on the results of the samples obtained during the dredging of sand. Table 9-1, shows the key information of the 6 tracks dredged in sand. As shown in Table 9-1, the period after the mixture in the hopper starts flowing over the overflow and the overflow level is adjusted is called the steady state situation. The duration of this period depends mainly on the soil conditions and therefore varies with each trip. However, note that in the initial phase of this steady state situation a set up time is present. During the first 2 to 4 minutes the overflow discharge increases from

zero to almost the value of the incoming discharge of both suction pipes. After this set up time, the steady state situation is reached.

Track ID	t _{start}	t _{overflow}	t _{end steady state}	t _{end dredging}	TDS data available	TDS Overflow losses computed	Dredging area.
1-105	07:13	07:28	07:49	08:28	+	Yes	Sandpit 6
3-106	12:43	12:58	13:08	13:34	+	Yes	Sandpit 5
6-108	13:28	13:40	14:10	14:24	+	No	Sandpit 5
8-112	06:19	06:32	06:43	07:03	+	Yes	Sandpit 5
11-113	13:27	13:40	14:02	14:13	+	No	Sandpit 5
14-115	10:20	10:32	10:52	11:05	+	Yes	Sandpit 5

Explanation symbols:

+ = available / +/- = data available but not used for set up sediment balance / - = not available

Table 9-1, overview TDS data

9.2.1 Analysis on concentrations dredging sand

For each sand trip, Table 9-2 shows the standard questions and the corresponding answers. First the concentrations of sediment in the initial 10 minutes of the overflow process are reviewed. One can assume that in this period of time an almost steady state situation exists. Four of the six sand trips show quite similar values. Furthermore, all samples indicate similar concentration values. The end of the steady state situation is not clearly marked by an increase or decrease of the obtained concentrations. However, during 3 trips the concentrations in the samples increase after the overflow was adjusted.

Focussing on the sample concentrations obtained during the entire trip, all samplers show an increase of concentrations in time. However, the bandwidth of this trend is large (for further information one is referred to chapter 10.2, statistical analyses). The results obtained by the two different methods of sampling (for the methods of sampling one is referred to Chapter 3.2) differ significantly. In addition to the different shapes of the concentration graphs obtained from the Flow-through samplers and the Bottle sampler, the concentrations captured by the Bottle sampler are significantly lower

Concentrations: dredging sand					
Track ID:	First 10 minutes of overflow period, flat curves are obtained.	Increase of Concentration in time during overflow period.	The FTS and BS samples show similar trends, similar shapes.	BS shows significant lower values during whole overflow period	The results presented by FTS show some correspondence: clustered
1-105	++	+-	+-	+-	++
3-106	++	+-	+-	+-	+-
6-108	++	+-	+-	++	+-
8-112	+-	+-	--	+-	--
11-113	++	+-	--	++	+-
14-115	--	++	+-	+-	--

Explanation symbols:

++ = certainly yes / +- = yes, but not very clear / -- = no, not at all
FTS = Flow Through Sampler / BS = Bottle Sampler

Table 9-2, concentration graphs sand tracks analysed.

during every trip. Especially trips 6 and 11 show this specific trend. In chapter 11 possible explanations are provided for these systematic deviations. The impact of level variations of the weir on the overflow measurements has been reviewed as well. During this specific research the results of all overflow samples by means of dry matter, d_{10} and d_{50} were reviewed at sudden weir-level drops, however no specific correlation was obtained.

9.2.1.1 Conclusions on concentrations dredging sand

The concentration of 6 sand-tracks was reviewed.

1. The samples taken by the Bottle sampler show lower values for the concentration of sediment than the Flow-through samplers. However in the initial phase of the overflow process the 2 sampling methods yield similar concentrations. The values vary between 10 and 40 kg/m³ with a corresponding overflow discharge of approximately 5 m³/s. Apparently, the same amounts of small particles are captured by both sampling methods.
2. The variations in concentration between the successive Bottle samples were significantly less compared to the Flow-through samples. This difference can be explained by the position of the Bottle sampler (chapter 11).

9.2.2 Analysis on particle size distributions

The approach used for the analyses of the concentration is also applied to the analysis of the Particle Size Distributions (PSD's). Since the analysis of the entire PSD in this stage of the research is too time consuming, some characteristic numbers are extracted from each PSD. Table 9-3 shows again the answers to three characteristic questions. The answers to these questions help to structure the results obtained during each track. The answers are based on the graphs of d_{10} , d_{50} and d_{60}/d_{10} presented in appendix 9.1 and 9.2.

Although the samples obtained by the Bottle and Flow-through samplers diverge, some similarities can be identified.

The d_{10} results per track (10 % of grains smaller than the corresponding sieve size of d_{10}) for both types of samplers show similar shapes during the 6 sand trips. The d_{10} values in 5 out of 6 trips vary little (4 – 6 μm) during the whole trip, only trip 105 shows an increase of d_{10} values after the steady state situation is ended. The variation between track 105 and the rest of the sand trip can be explained by the conditions of the dredged soil; track 105 is the only trip that is dredged near Sand Pit no 6; the remaining trips were dredged at Sand Pit 5 (see appendix 9.1 and 9.2).

The d_{50} values of the sand tracks show less correspondence. Four out of six tracks start with d_{50} values of approximately 20 to 50 μm . The remaining two tracks show in the initial phase of the overflow period values ranging from 5 to 150 μm . The maximum d_{50} measured during all tracks is about 200 μm .

The fluctuations of d_{10} and d_{50} for the Flow-through samples are significant compared to those obtained with the Bottle sampler.

Particle Size Distributions: dredging sand															
Track ID:	Amounts passed particular sieve size: increase/decrease or equally in time.						Stability in time (is signal highly fluctuated?).						Generally differences between FTS and BS. (FTS >, &, < BS)		
	FTS			BS			FTS			BS			d ₁₀	d ₅₀	d ₆₀ /d ₁₀
	d ₁₀	d ₅₀	d ₆₀ /d ₁₀	d ₁₀	d ₅₀	d ₆₀ /d ₁₀	d ₁₀	d ₅₀	d ₆₀ /d ₁₀	d ₁₀	d ₅₀	d ₆₀ /d ₁₀			
1-105	--↑	--↑	↑↓	--↑	--↑	--↑	+	+	+	+	+	+	>	>	&
3-106	--	--↑	↑	--	--↑	--↑	-	+	+	-	-+	-+	&	>	>
6-108	--	--↑	--	--	--	--	-	+	-	-	-	-	&	>>	&
8-112	--	↑↓	--	--	↑↓	--	-	+	+	-	-+	-	&	>	&
11-113	--	--↑	--	--	--↑	--	-	+	-+	-	-	-	&	>	&
14-115	--	↑↓	↑↓	--	↑↓	↑↓	-	+	+	-	-+	-+	&	>	&

Explanation symbols															
FTS = Flow-through samplers BS = Bottle samplers.															
↑ = increase in time / -- = equally in time / ↓ = decrease in time / --↑ first steady after approx. 10 min increase															
- = Stable / -+ = small fluctuations / + = highly fluctuated.															
> = FTS values are more or less greater than BS values / >> = FTS values are much greater than BS values /															
& = FTS are almost identical to BS values															

Table 9-3, d₁₀, d₅₀ and d₆₀/d₁₀ further analysed.

The Uniformity Coefficients (d₆₀/d₁₀) of the different tracks are highly variable. The maximum values of the Uniformity coefficient are about 30, the minimum values are occasionally less than 5 (well graded sample). No trend can be observed in the variation of the uniformity coefficient during the 6 sand tracks.

From theory one should expect the settling effect of large particles and the wash out of fine materials into the Bottle sampler (ref. Rijn, L.C. van, & Schaafsma 1986). When reviewing the sampling results and focussing on the Uniformity coefficient, this theory is not proven. It appeared that the coarse grains were not trapped.

9.2.2.1 Conclusions on the particle size distributions dredging sand

1. The d₁₀ values appeared to be similar for almost all sand trips in the same dredging area (sandpit 6); the results of the samples obtained by the Flow-through samplers tend to be slightly (up to 3 µm) higher than the results presented by the Bottle sampler.
2. Again the Bottle sampler's results are generally lower compared to the samples obtained from the Flow-through sampler.
3. The d₁₀ and d₅₀ curves obtained from the Bottle sampler appeared to have less fluctuations compared to the d₁₀ and d₅₀ values obtained from the other Flow through samplers. The d₅₀ values obtained by the Bottle sampler tend to be a little less comparing to the d₅₀ values obtained by the Flow-through samplers.
4. Concerning the steady state period (varying from 10 to 30 minutes per trip), no particular trends in the particle size distributions can be observed.
5. The Uniformity coefficient does not show any consistent results in time.

9.3 Dredging Silt

In this paragraph we will focus on the results of the samples which were taken during 7 silt dredging trips and 1 trip in mixed materials.

Track ID	t _{start}	t _{overflow}	t _{end steady state}	t _{end dredging}	TDS data available	Overflow loses computed	Dredging area
2-8	09:58	10:22	t _{end dredging}	10:45	+	Yes	Maasmond
4-107	08:11	08:25	08:55*	09:10	-/+	Yes	Maasgeul
5-15	10:49	10:24	t _{end dredging}	11:51	--	No	Maasmond/sea
7-16	15:53	16:12	t _{end dredging}	16:34	+	Yes	Maasmond
9-23	08:31	08:54	t _{end dredging}	09:07	+	Yes	Maasmond
10-24	11:13	11:34	t _{end dredging}	11:52	+	Yes	Maasmond
12-29	05:09	05:34	t _{end dredging}	05:57	+	Yes	Maasmond
13-30	07:55	08:19	08:29	08:34	+	Yes	Maasmond

Explanation symbols

+ = available / +/- = data available but not used for set up sediment balance / - = not available

Table 9-4, overview TDS data, dredging silt.

As shown in Table 9-4, during almost all trips the overflow weir level was not adjusted. Consequently the incoming flow velocities and the discharge at the overflow can be assumed constant. Besides the constant level of the overflow, the duration of the overflow period was significantly less than it was when dredging sand. The short overflow period is caused by the high concentrations of the silt mixture discharged by the overflow. Therefore it is not worth to continue dredging because almost the same amount of material coming into the vessel is released by the overflow.

9.3.1 Analyses concentrations

The concentrations obtained with the samplers while dredging silt indicate significantly higher values compared than the concentrations obtained during dredging sand. For the analyses of the results, an approach identical to the one in the previous section was used. However because of the different soil conditions at the dredging areas, the standard questions have been adjusted.

For all dredged tracks in silt and mixed sand-silt soils the concentration of sediment increases in time. The maximum obtained concentrations were about 2 to 3 times higher than the values obtained during dredging sand. This is due to the fact that small particles take more time than large particles to settle.

It is clearly visible that the mixed trip is "spoiled" with the presence of sand. In the initial phase of the dredging process, all samplers show about the same concentrations. However after 14 minutes the presence of sand become visible in the variations between the Flow-through and Bottle sampler results.

The fluctuations between successive samples (taken by Both bottle as Flow-through samplers) are much less compared to the results of the samples during dredging sand. Again, the relatively small particles are responsible for these results.

Despite the fact that the concentrations obtained by using the Bottle sampler, were significantly less than the concentrations captured by the Flow-through samplers, the

shapes and trends of both concentration graphs in the course of the overflow period show some correspondence. Focussing on the Flow-through samplers only the results appeared to be quite similar. No specific trends could be distinguished.

Concentrations: dredging silt					
Track ID:	Increase of Concentration in time during overflow period.	The FTS and BS show similar trends, similar shapes.	BS shows lower values during whole overflow period.	Maximum difference between BS and FTS concentration values. [kg/m ³]	The results presented by FTS show some correspondence: clustered
2-8	++	-	++	100	++
4-107 M	++	++	++	112	+-
5-15	++	++	++	45	++
7-16	++	+-	++	75	++
9-23	++	++	++	55	++
10-24	+-	+-	++	210	+-
12-29	++	+-	++	90	+-
13-30	++	++	++	95	++

Explanation symbols.

++ = certainly yes / +- = yes, but not very clear / -- = no, not at all
 FTS = Flow Through Sampler / BS = Bottle Sampler / M = Mixed sand-silt

Table 9-5, concentrations, graphs sand tracks analysed.

9.3.1.1 Conclusions on concentrations dredging silt

1. The concentrations captured by both samplers during the silt dredging show more consistent (less fluctuations) values compared to the concentrations measured during sand dredging. Moreover the concentrations captured by both type of samplers show an increase in time during almost all silt trips.
2. Nearly all samples in the silt trips taken by the Flow-through samplers show similar concentration values. The conclusion can drawn that the position of the Flow-through samplers on the overflow funnel is not important, this conclusion should be verified during the statistical analysis of the overflow samples (chapter 10).
3. The Bottle sampler shows significantly lower values of concentration compared to the Flow-through samplers. As shown in Table 9-5 variations between the results of the Flow-through samplers and the Bottle sampler run up to 200 µm, moreover no consistent deviations between both methods are observed.

9.3.2 Analyses particle size distribution

Table 9-6 shows the evaluation of the particle size distributions. We will start with the interpretation of the d_{10} values. Quite similar results are obtained for the d_{10} values of all trips. Only the d_{10} values taken during the mixed soil trip are different. Also, the d_{50} values taken by the different samplers appear to be quite similar. Track 5-15 was dredged more seawards (see also appendix 9.1, maps of tracks) compared to the other silt tracks. Therefore, more coarse material was captured. During many silt trips small variations between the Bottle sampler and Flow through sampler were present. During these trips, the Bottle sampler tends to obtain the smallest d_{50} values.

It appears that the Uniformity coefficient has a relation with the soil conditions. When dredging in silt, the coefficient has values of about 5 to 7. Moreover, it appeared that during trips dredged more seawards, the coefficient increased to about a value of 20, (badly sorted). We already discovered these values when sand is dredged.

Particle Size Distributions: dredging silt															
Track ID:	Amounts passed particular sieve size: increase/decrease or equally in time.						Stability in time (is signal highly fluctuated?).						Generally differences between FTS and BS. (FTS >,&,<BS)		
	FTS			BS			FTS			BS			d ₁₀	d ₅₀	d ₆₀ /d ₁₀
	d ₁₀	d ₅₀	d ₆₀ /d ₁₀	d ₁₀	d ₅₀	d ₆₀ /d ₁₀	d ₁₀	d ₅₀	d ₆₀ /d ₁₀	d ₁₀	d ₅₀	d ₆₀ /d ₁₀			
2-8	--	--	--	--	--	↑↓	-+	-+	-	-	-	-	&	&	&
4-107M	↑↓	↑↓	↑↓	--	↑↓	↑↓	+	+	+	-	-+	-+	>>	>	<
5-15	--	↑↓	--	--	↑↓	--	-	-+	-	-	-+	-	&	>	&
7-16	--	--	--	--	--	--	-	-	-	-	-	-	&	&	&
9-23	--	--	--	--	--	--	-	-	-	-	-	-	&	&	&
10-24	--	--	--	--	--	--	-+	-+	-+	-	-+	-+	&	&	&
12-29	--	--	--	--	--	--	-	-	-	-	-	-	&	&	&
13-30	--	--	--	--	--	↓	-+	-	-+	-	-	-	&	&	&

Explanation symbols
↑ = increase in time / -- = equally in time / ↓ = decrease in time / --↑ first steady after approx. 10 min increase
- = Stable / -+ = small fluctuations / + = highly fluctuated.
> = FTS values are more or less greater than BS values / >> = FTS values are much greater than BS values / & = FTS are almost identical to BS values

Table 9-6, PSD's analysed, dredging silt.

9.3.2.1 Conclusions on particle size distributions dredging silt

1. The d₁₀ and the d₅₀ values obtained when dredging silt appeared to be quite similar for both sampling methods.
2. The seabed material directly influences the Particle Size Distribution of the overflow. However the dependency and relations between both soil and overflow samples is not yet quantified.
3. Even the Uniformity coefficient shows quite steady values, during the trips performed on silty soils.

9.4 Overall conclusions sampling results overflow

In this chapter, all samples taken during 14 tracks were reviewed. The most important conclusions of this analysis are summarised in this paragraph.

Sand and Silt dredging:

1. For both sand and silt trips it appeared that the smaller the grain sizes in the overflow mixture, resulted in more homogeneous overflow conditions. Consequently fewer fluctuations in the sampling results are obtained.
2. When only small particles are present in the overflow funnel, the Bottle sampler results are about similar to the Flow-through sampler results.

3. Generally speaking for both concentration and the Particle Size Distributions, the Bottle sampler yields smaller values than the Flow-through samplers.
4. No relation is present between the concentrations collected with the Flow-through samplers and the Bottle sampler.

Sand dredging:

5. When sand dredging, the Flow-through samplers generally show an increase of concentration in time, the Bottle sampler shows this trend only for some tracks. That makes the results of the Bottle sampler rather suspicious.
6. The d_{10} and d_{50} curves obtained from the Bottle sampler appeared to have less fluctuations compared to the d_{10} and d_{50} values obtained from the other Flow through samplers. The d_{50} values obtained by the Bottle sampler tend to be a little less comparing to the d_{50} values obtained by the Flow-through samplers.
7. The d_{10} values obtained by both sampling methods, appeared to be quite similar for almost all sand trips in the same dredging area (sandpit 6); the results of the samples obtained by the Flow-through samplers tend to be slightly (up to 3 μm) higher than the results presented by the Bottle sampler.

Silt dredging:

8. The d_{10} and the d_{50} values obtained when dredging silt appeared to be quite similar for both sampling methods. Thereby both methods show an increase of concentration over time. This conclusion is based on the graphs stated in appendix 9.2.
9. The concentration values shown by the three Flow-through samplers appeared to be consistent in time as well. Nearly all samples in the silt trips taken by the Flow-through samplers show similar concentration values. The conclusion can drawn that the position of the Flow-through samplers on the overflow funnel is not important, this conclusion should be verified during the statistical analysis of the overflow samples (chapter 10).
10. The Bottle sampler shows significantly lower values of concentration compared to the Flow-through samplers. As shown in Table 9-5 variations between the results of the Flow-through samplers and the Bottle sampler run up to 200 μm , moreover no consistent deviations between both methods are observed.

To conclude, the explanations behind the obtained results still form our main interest. To fulfil this interest, a statistical analysis will be performed in the next chapter no. 10. Besides this statistical approach, in chapter 11 the results of the overflow samples will be analysed by taking the physical characteristics of the vessel into account. For example, the impact on the overflow of characteristics such as trim, the hopper volumes and height of the overflow weir.

10 Statistical analyses

10.1 Introduction

So far a simple data assessment has been applied for the analysis of the TNO results. In this chapter we will focus on the statistical analyses of the overflow data. For every overflow sample TNO determined the dry matter content and the Particle Size Distributions (PSD). From these data, the characteristic numbers are extracted which will be used as the input of this analysis.

As earlier stated in the introduction of this thesis, the TASS software is developed to draw up relations for the source terms of sediment plumes caused by the dredging process in the vicinity of a TSHD. Many mechanisms contribute to these source terms, the overflow of sediment of a TSHD is considered to be the main contribution to the sediment plumes. When the source term is known, it can be used as input for dynamic and passive plume models, plumes can be calculated and verified by measurements (like ADCP). In chapter 8 an attempt is made to compute the source term by the set up of a volume and sediment balance of the vessel during dredging. The results of these computations appears to be not that accurate that the overflow source term can be calculated with any sufficient level of accuracy.

In chapter 9 the results of the overflow measurements are reviewed for every single trip. From this analysis already some trends and relations between the samplers, soil conditions and the loading processes were obtained. However, these relations were not proved by numbers. In this statistical chapter the focus will be really on the consistency of the measuring results by numbers, because only when the consistency of the measurement is proved, they can be used for some description of the overflow source term.

Before commencing the statistical analysis of the overflow data, one should note the context in which this chapter is placed. In an ideal situation the statistical analysis will tell us how many samples are needed to gain a defined level of confidence in calculated averages of parameters describing the overflow. To establish this level of confidence, clear conditions should be stated to relate these measured values on. These conditions are in this stage of the TASS campaign not known yet, that is the reason why we will focus only on the consistency of the data in this statistical analysis.

Because of the fact that that not all sampling data was available in the initial phase of the research (because of the staged commissioning of sample testing) two approaches were adopted for this analysis. First, the results of 6 tracks will extensively be analysed on their mean values, ranges, standard deviations and correlation coefficients. This initial research is called the "Basic analysis" (Figure 10-1). One of our main interests for

performing this analysis is to determine whether the results of the Flow-through samplers correlate with each other. Therefore for each track the correlation between the 3 Flow-through samplers is quantified. The result of this research determines the strategy for the second phase analysis: the batch analysis of all overflow samples. Because of the results of the Basic analysis, in this new strategy (second phase analyses) it is decided not to focus on the analyses per track any further.

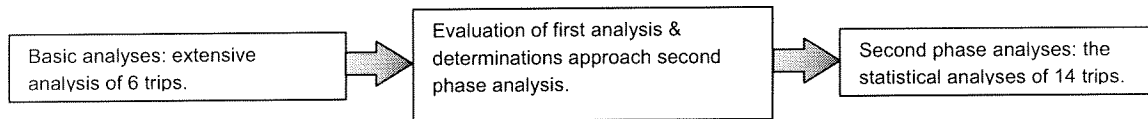


Figure 10-1, statistical analysis approach.

At the end of this chapter the method of analysis will be evaluated. Secondly the statistic trends will be summarised and conclusions drawn.

10.1.1 The corresponding appendix

A selection of the results, in the form of by graphs and statistical numbers is presented in this chapter. The complete set of results from the TNO analysis is presented in the corresponding appendix 10.2. This appendix is divided into 7 paragraphs, the contents of which are listed below.

1. The obtained d_{50} results of 6 trips are correlated to the Side Flow-through sampler.
2. The concentrations of 6 trips are correlated to the Side Flow-through sampler.
3. The d_{10} , d_{50} d_{90} and the d_{60}/d_{10} values of all samplers of *sand trip 106* are correlated to the Aft-sampler.
4. The d_{10} , d_{50} d_{90} and the d_{60}/d_{10} values obtained by samplers during *sand trip 106* are correlated to the Side-sampler.
5. The d_{10} , d_{50} d_{90} and the d_{60}/d_{10} values obtained by samplers during *silt trip 24* are correlated to the Side-sampler.
6. The concentrations against the d_{50} values are correlated with each other for *sand trip 106* and *silt trip 24*.
7. An overview is shown of all computed statistical numbers of both Basic and Second phase analyses.

The decision to use *sand trip 106* and *silt trip 24* for the more extensive analysed was based on logistical reasons. These results of these samples were already available in the initial phase of the research.

10.2 Basic analyses

As stated in the introduction, the results of the samples taken during 6 trips are used for this basic analysis. In total 14 tracks are available for the entire study. The remaining 8 tracks are taken into account in the second phase analyses.

Table 10-1, shows the approach applied for the 6 trips of this basic analysis. During almost every trip 4 samplers were used.

The number of samples depended on the sampling rate and the overflow period. The results of the laboratory analyses serve as data input for this statistical analysis. Most of the statistical numbers are easy to understand, however the determination of the correlation coefficient (Corr (x,y)) needs explanation. Therefore only this number will be discussed more detailed, the rest of the equations are listed below.

Tracks no.	Track ID	Sampler ID:	Input	Results statistical computations:
1	4-107 mixed	Aft	→	$\mu, \sigma, \text{Max}, \text{Min}, \text{Range}, \text{Range}_{\text{mean}}, \text{Corr}$
		Side	→	$\mu, \sigma, \text{Max}, \text{Min}, \text{Range}, \text{Range}_{\text{mean}}, \text{Corr}$
		Front	→	$\mu, \sigma, \text{Max}, \text{Min}, \text{Range}, \text{Range}_{\text{mean}}, \text{Corr}$
		Centre	→	$\mu, \sigma, \text{Max}, \text{Min}, \text{Range}, \text{Range}_{\text{mean}}, \text{Corr}$

Table 10-1, example approach analyses of one of the six trips.

Mean values (μ)

$$\mu = \frac{\sum_{i=1}^N x_i}{N}$$

Equation 10-1, mean value.

Standard deviation (σ)

$$\sigma = \sqrt{\frac{\sum_{i=1}^N (x_i - m_x)^2}{N - 1}}$$

Equation 10-2, standard deviation.

The ranges:

$$\text{Range} = \text{Max}_{\text{value}} - \text{Min}_{\text{value}}$$

Equation 10-3, standard range.

$$\text{Range}_{\text{mean}} = \frac{\text{Max}_{\text{value}} - \text{Min}_{\text{value}}}{\mu}$$

Equation 10-4, adjusted mean range.

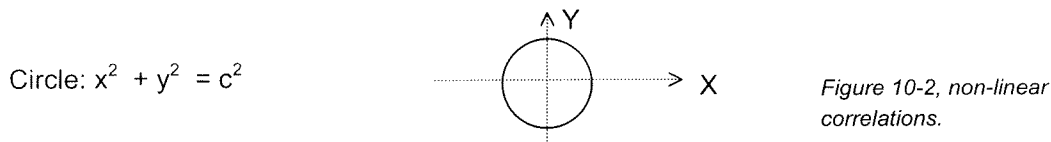
Correlation coefficient

One of our main interests during this specific research is to determine whether, and how, the different samplers (and positions) are correlated. Therefore, the results per sampler will be compared, focussing on the concentrations and the d_{50} -values per sample. The d_{50} value is chosen because this value is considered to be the representative value of the entire Particle Size Distribution per sample.

For two trips also the d_{10} , d_{90} and d_{60}/d_{10} are used as input for the computations in order to verify the influence of using only the d_{50} as representative value of the Particle Size Distribution.

At the end of this basic analysis, the correlations between the 4 samplers will be determined.

For the quantification of these linear relations, the correlation coefficient is applied. This coefficient quantifies the linear dependency in-between two stochastic variables. When no linear relation exists between two samplers the correlation coefficient is zero. However, sometimes a relation can be present which is non linear. A good example of this is the circle: $X^2 + Y^2 = C^2$. All variables depend 100 % on each other. However the variables are not correlated.



The computation of the linear correlation coefficients is performed by using Equation 10-5.

$$\rho(X, Y) = \frac{\sum_{i=1}^n (x_i - m_x)(y_i - m_y)}{\sqrt{\left\{ \left(\sum_{i=1}^n (x_i - m_x)^2 \right) \cdot \left(\sum_{i=1}^n (y_i - m_y)^2 \right) \right\}}} = \frac{Cov(X, Y)}{\sqrt{Var(X)Var(Y)}} \quad \text{Equation 10-5, correlation coefficient.}$$

Since the spatial position of the Flow-through Side sampler lies in-between the Front and Aft sampler, it has been decided to correlate the rest of the samples to this side sampler. The validity of this decision will be evaluated in this chapter.

One can hypothesise that the samples taken by the centre-bottle-sampler are positioned more centrally and are therefore better to correlate. However, the results (Figure 10-3) of the bottle sampling method diverge from those of the three Flow-through sampling methods. As we already discovered in the previous chapter, particularly when dredging sand the results of the centre-Bottle sampler do not seem consistent with those of the Flow through samplers. Therefore, the results of this sampler are not used in the statistical analysis. It should be pointed out, however, that this does not mean that the Flow-through samplers are better.

Concentrations trip: 3-106_sand

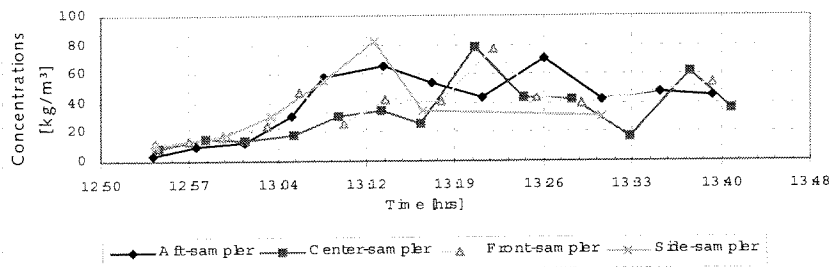


Figure 10-3, Example of concentrations, Aft, Side, Front and Centre samplers.

10.2.1 Simplifications and initial conditions

Before commencing the statistical operations some remarks and simplifications are made. These simplifications are essential for the set up of the statistical computations but unfortunately they affect the validity of the results of these statistical operations.

1. For the computations of correlations between two samplers, the results obtained within bandwidths varying from a minimum of 1 to a maximum of 3 minutes. Linear interpolation between two successive measured values is not possible because of the irregularities in the measured values of the concentrations and d_{50} values.
2. Correlation coefficients of almost 1 indicate a strong relation between the results of two samplers. However the amount of data is also important for the reliability of this judgment. (For example the correlation of two points is always 1, obviously it is incorrect to draw the conclusion that these two points are strongly related.)
3. The correlation coefficient can only be calculated for two matrices of identical size. Because of variations in the sampling interval per sampler not all samplers yielded the same amount of data. Therefore the sampler with the smallest amount of samples determines the size of the correlation matrix.

		Side samples				
Front samples	Sample no:	1	2	3	4	5
	1	Corr	Corr	Corr	Corr	Corr
	2	Corr	Corr	Corr	Corr	Corr
	3	Corr	Corr	Corr	Corr	Corr
	4	Corr	Corr	Corr	Corr	Corr
	5	Corr	Corr	Corr	Corr	Corr
	6	Corr	Corr	Corr	Corr	Corr
	7	Corr	Corr	Corr	Corr	Corr
	8					

Table 10-2, example, the side sampler determines the size of the correlation matrix

4. To draw up correlations in Particle Size Distribution the d_{50} is used instead of the shape of the entire particle size distributions.

5. Because not all tracks were available in the initial phase of this study, only six tracks were used for the Basic analysis.
6. The results obtained by the Bottle sampler are not taken into account. It appeared that these results were not representative of the overflow consistency (chapters 6, 9.2 and 11).

10.2.2 Results basic analysis

In this paragraph the results of the statistical analyses will be presented. For the quantification of the results several methods are used. First, the mean values and standard deviation will be reviewed. Second, we will go into the ranges per sampler. Third, the correlations between different Flow-through samplers will be discussed. All results are presented in appendix 10.1 and 10.2.

10.2.2.1 The mean values and standard deviations

As stated before, the results obtained per sampler are evaluated on their mean values and the standard deviations. The mean values tell us what the average value of the obtained data is (Both d_{50} and concentration values), the standard deviations tell us how this specific data is spread.

When taking the results of chapter 9 into account, the results of this statistical comparison seem obvious. The mean values of the concentrations when dredging silt was much larger compared to the concentrations during sand dredging. Reviewing the mean values, the d_{50} , showed similar variations. For example, the mean values of the d_{50} while dredging sand were about 3 to 8 times higher than the d_{50} obtained while dredging silt.

Also, the mean values per track, dredging on sand and silt soils for every sampler were reviewed. Concentrations and d_{50} values obtained by the Flow-through samplers appeared to be of the same magnitude. The Bottle sampler results show during sand dredging for both parameters significant smaller mean values. During silt dredging not such a differences were found.

The standard deviation does not show us consistent results either. The following relations are researched:

1. The variation coefficient per sampler, for every track (mean value, divided by the standard deviation).
2. Standard deviations variations of the data obtained per track.

However it worth mentioning that during dredging silt the standard deviations tend to show up the smallest values for both concentration values as for the d_{50} values. This implies that the variations in data during dredging silt are less than the variations in the data obtained during dredging sand. However, it should be noted that during silt dredging fewer samples were taken because of the relatively short overflow period. These results would be better if the number of silt overflow samples had been similar to the number of sand overflow samples.

10.2.2.1.1 Conclusions

The statistical research concerning the mean values and standard deviations did not add much to the information we already extracted from the plain analyses of the of the sampler results (chapter 9). The Bottle sampler results tend to show the smallest values for the dry matter and d_{50} values, however the validity of this hypotheses has not been established. To make this clear, more trips should be analysed.

10.2.2.2 The ranges

The range of data per track is defined as the maximum value minus the minimum value. Figure 10-4 illustrates the range of the Bottle sampler data set, obtained during dredging sand. As shown in appendix 10.2, the range has been determined for both the concentrations and d_{50} values of 6 tracks.

This method extracting the ranges per type of sampler is sensitive for unusual (up to 4 times the average values) measured values, which are not representative for the overflow current. This is caused by the fact that measuring errors immediately determine the maximum or minimum border of the range. Of course such ranges are not representative for the whole sampler data set.

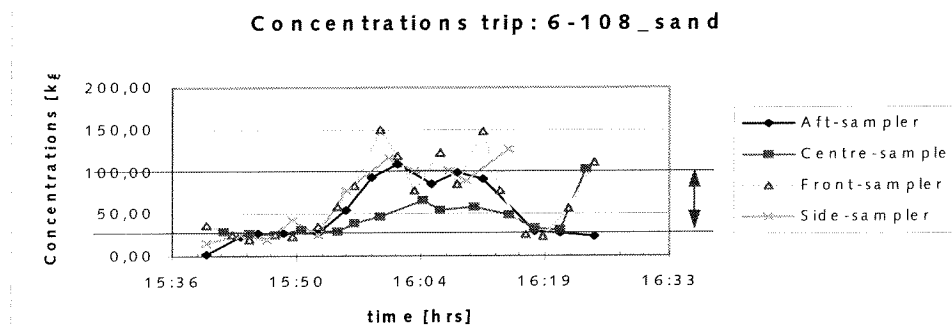


Figure 10-4, Example of the bandwidth of the Bottle sampler results.

In order to find a solution for extraction of more representative ranges from the data, two ideas were investigated. In the first, all statistical outliers were deleted. The outliers (X_i) are defined as all data point values, which are greater than the mean values of the dataset added by two times the standard deviations ($X_i > \mu \pm 2 \cdot \sigma$); this corresponds with the 5 % percent outliers of the data set. In general, after such an adjustment, a more homogeneous data set will be obtained. However, this method is not suitable, due to the lack of data and the fact that most outliers are already deleted because the values where of such magnitude that they appeared not to be realistic. Probably stones were captured by these samples

A better way to compare the bandwidths of all tracks is to relate the range to the mean values of the sampler. Therefore the ranges are divided by the corresponding mean values (Equation 10-4). Moreover the entire data set is used. This approach appeared to be more successful and was therefore applied for further analyses.

10.2.2.2.1 Conclusions obtained ranges

Concentrations

Regarding the "Range/mean" values, the sand tracks show, as expected, the largest bandwidths (because of the large fluctuations between the successive samples). The values vary between 0.92 to 2.6 [-] for the 4 samplers while dredging sand. When dredging silt, values vary between 0.5 to 1.0 [-]. The larger the range/mean values, the larger are the irregularities related to the particular mean value. These numbers show that because smaller irregularities are obtained while dredging silt, the "Range/mean" numbers are smaller comparing while dredging sand. Therefore one can conclude again that when dredging silt a more homogeneous overflow mixture is present.

d_{50} values

Again the silt samples show the lowest "Range/mean" values. Even bandwidths up to 1/5 of the original values of the sand samples are obtained.

Generally the analyses of the ranges only us tells that the ranges of the concentrations and the d_{50} values during sand dredging are much larger than during silt dredging. A reasonable explanation can be found in the consistence of the sand and silt mixtures. As far as the sand mixtures are concerned it might be very common that large variations occur.

10.2.2.3 Correlations

As initially stated in the first attempt to correlate the 3 Flow-through samplers to each other, the samplers were correlated with the Side-sampler. The correlations were researched in time and space simultaneously by using different parameters. Table 10-3 shows the characteristic parameters on which this analysis is performed. For instance the specific d_{50} value obtained from the Front-and Aft-samplers of 6 trips is correlated to the Side-sampler.

nr.	Track ID.	D ₁₀	D ₅₀	D ₉₀	D ₆₀ /D ₁₀	Dry Matter	Dry Matter vs. D ₅₀
1.	4-107_mixed	-	Yes	-	-	Yes	Yes
2.	5-15_silt	-	Yes	-	-	Yes	-
3.	6-108_sand	Yes	Yes	Yes	Yes	Yes	Yes
4.	10-24_silt	Yes	Yes	Yes	Yes	Yes	-
5.	11-113_sand	-	Yes	-	-	Yes	-
6.	12-115_silt	-	Yes	-	-	Yes	-

Table 10-3, parameters used in correlation coefficient computations

Ideally sampling results should be correlated on time and space separately, therefore the samples should be taken simultaneously, however thy were not. Table 10-3 shows evidently that the correlation coefficients are not computed for all parameters. This is because the results of the pilot computations (trips 6 and 10) did not show any correlations in-between the samplers (appendix 10.1).

10.2.2.3.1 Correlations by concentrations

When reviewing the correlations of the concentrations of the different samplers, the correlation coefficients taken during the dredging of silt, tend to be higher than those taken during dredging of sand. An example of these stronger relations is shown in

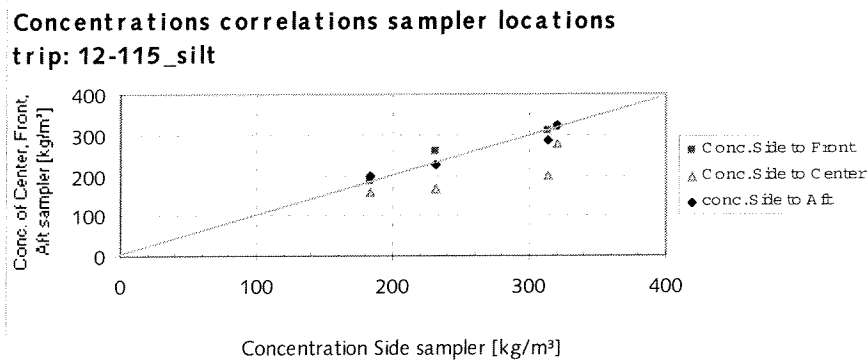


Figure 10-5, correlations of the concentrations during dredging silt.

Figure 10-5. However the amount of data is not sufficiently large to derive further trends from these coefficients.

It is also worth mentioning that already during the plain analysis (chapter 9) of the samples the results obtained during dredging silt were quite consistent.

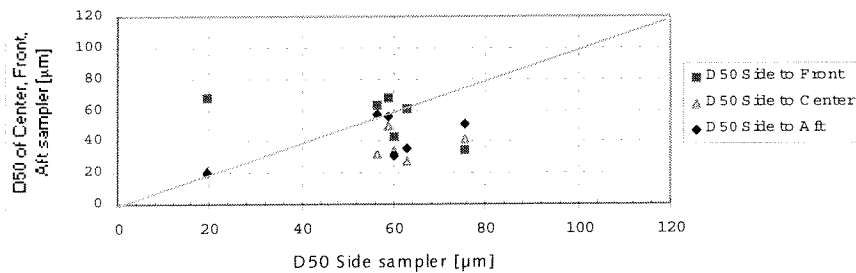
10.2.2.3.2 Correlations d_{50} values only

As stated in Table 10-3 the d_{50} values from 6 trips were used as basic values for the computation of the correlation coefficient. These values are considered to be the most representative values in characterising the Particle Size Distribution. It appeared that the correlation between the different samplers, while dredging sand, was far from consistent and therefore useless for further research. The correlation between the different samplers while dredging silt appeared to be more promising. However, because of the earlier defined sampling intervals and the high level of turbulence in the flow at the sampling location this comparison also did not work out. The graphs presented by Figure 10-6 show the correlation of two random trips and it is clear that no significant correlations are obtained.

10.2.2.3.3 Detailed analyses

Besides the correlation based on the d_{50} values, two tracks nr. 106 (sand) and nr. 24 (silt) have been analysed in more detail. During this pilot analysis, the correlation of the Flow-through samplers was computed by using d_{10} , d_{90} and d_{60}/d_{10} values. First the side sampler was used as the central correlation sampler; second the Aft sampler was defined as the sampler to correlate the rest of the samplers to. Then the Aft-sampler is taken as central sampler position, in the 4th place the Side-sampler was the central sampler.

Correlations sampler locations based on D50 values
trip: 5-15_silt



Correlations sampler locations based on D50 values
trip: 11-113_sand

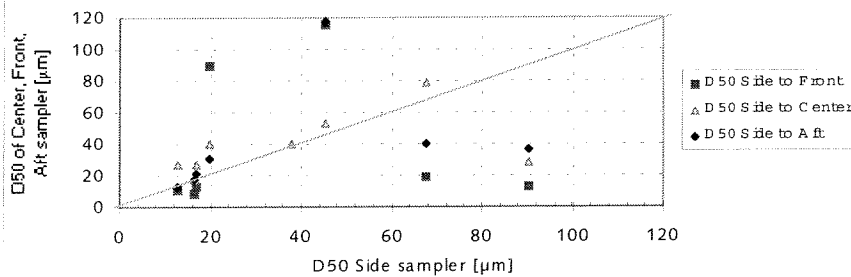


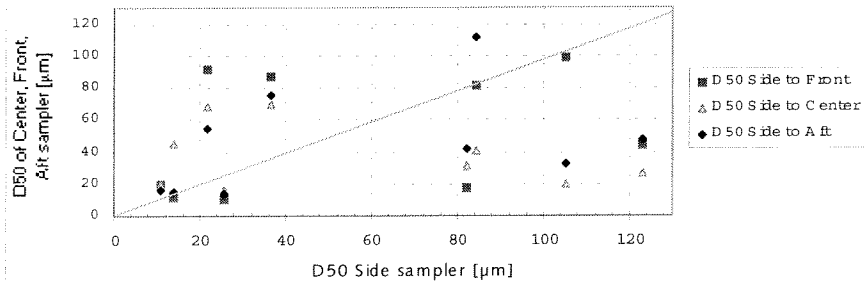
Figure 10-6, correlations d_{50} . during dredging silt and sand.

10.2.2.3.4 Correlations Concentrations vs. d_{50} values

For most of the silt tracks negative correlation coefficients have been obtained. This implies, for example, that an increase of d_{50} results in a decrease of concentrations. However this relation is not shown for all the silt tracks. For sand dredging the correlations tend to be positive. In some cases the Front, Side and Aft samplers show correlation coefficients of 0.7 to 0.9. However, negative correlations of 0.28 have also been obtained. Consequently, no specific trend has been found.

Figure 10-7 shows the differences when the side sampler is used as central correlation samplers. Unfortunately, this comparison did not produce any improvements. For one sand trip the results of this comparison are shown in Figure 10-7. Again, the green line shows the correlation, with 100% correlations corresponding to a correlation coefficient of 1.

Correlations sampler locations based on D50 values
trip: 6-108_sand



Correlations sampler locations based on D50 values
trip: 6-108_sand

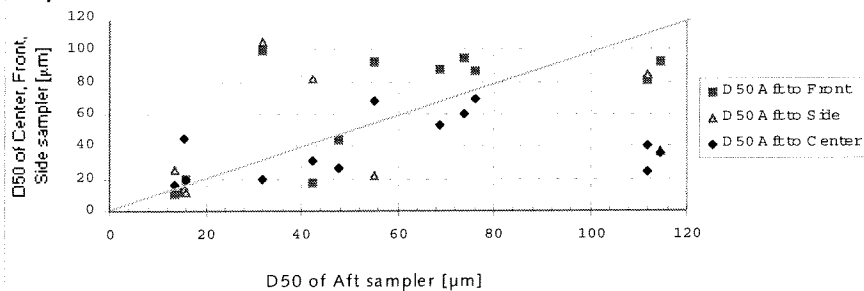


Figure 10-7, The Aft and Side samplers as central correlation samplers.

10.2.3 Conclusions basic analysis

1. Focussing on the correlations between the Flow-through samplers in time and space, not any clear statistical trends are obtained. There may be three reasons for this:
 - Strong correlations are masked because of lack of data.
 - Moreover, the fact that the samples have not been taken simultaneously makes it difficult to obtain reliable results from the analysis. Bandwidths for samples taken in the specific defined time-period (paragraph 10.2.1) of up to 3 minutes are large compared to the time scale of the fluctuations at the overflow.
 - Because the samplers are not taken simultaneously it is not known if the samplers are correlated in time or space. Probably both elements exert their influence on the correlations.
2. The concentrations and d_{50} values show a slightly better correlation between the samplers during the dredging of silt than during the dredging of sand.
3. Reviewing the amounts of dry matter captured by the 4 samplers, the Flow-through samplers yield the highest values. We already discovered this trend in the previous chapter. However, by this statistical analysis a decisive conclusion cannot be made yet, for this purpose more trips should be reviewed.
4. Mapping the maximum and minimum values obtained by the different samplers did not help to describe the different sampling ranges.

5. The ranges while dredging silt were significantly less compared with dredging sand. This is the most important conclusion to be mentioned. This conclusion is confirmed because the homogeneity of the silt mixture is much better compared with the sand mixtures.

As earlier stated no significant discoveries with respect to the statistical trends and correlations during a dredging sequence are drawn from the statistical analysis so far. Therefore, it is decided to shift the focus away from the results per trip. Instead of these trip analyses, the analysis of the entire data sets combined could provide more insight in the results of the samplers. Moreover because no correlations between the samplers were found, it seems that it does not matter which Flow-through samplers are used.

10.3 Second phase Analysis

From the conclusions of the basic analyses a second method of analysis is developed, focussing on the batch data sets of 14 tracks (467 samples). Because the results of the analysis of correlations between the different sampler positions did not show any consistency, we focus during this analysis on the mean values and standard deviations only. One should bear in mind that in this chapter only the processes on a global level are reviewed. Therefore the results cannot be used to determine the instantaneous values at the overflow.

The analysis is structured as follows:

- Step 1 The computation of mean values and standard deviations of sand, silt and mixed trips separated.
- Step 2 Identical to step 1, but now the results per soil condition are analysed per sampler location in the overflow.

The results of these computations are stated in appendix 10.3.

10.3.1 Results of step 1

During this second approach, the analysis is focused on the three types of soils separately.

Soil conditions (nr of samples)	Dry matters [kg/m ³]		d ₅₀ values [µm]	
	Mean values	Standard deviations	Mean values	Standard deviations
Sand (280)	49	30	73	57
Silt (130)	282	82	21	20
Mixed (54)	121	88	118	45

Table 10-4, results second phase analyses, step 1.

At first sight, the relations between the d₅₀ values and the concentrations seems trivial, the smaller the mean d₅₀ diameter of the particles, the greater the concentration values captured by the samplers. However, when dredging in mixed soil conditions, smaller dry matter values are obtained while large mean d₅₀ numbers were present. It appears that the relation between the particle sizes and dry matter content does not depend only on the d₅₀ value. Taking the entire Particle Size Distribution into account could provide more insight in the process.

Focussing on dry matter only, the smallest standard deviations (related to the mean values) are obtained while dredging silt. We already discovered in the previous chapter that when dredging in these types of soil consistent dry matter values were measured. The d₅₀ values show more variation, probably the variations in Particle Size Distribution is much larger compared to the variations of the concentration values.

10.3.2 Results of step 2

Now we focus on the results of the measurements of the different samplers. The results of this research are stated in Table 10-5, focussing on these results we will try to answer the following questions, which are important for the evaluation of the sampling system used.

The samplers:

1. What values did the Bottle sampler measure compared to the Flow-through samplers?
2. Do we need to sample on different location in the overflow? What can be said about the number of samples per trip?

Dry matter and d_{50} values:

1. Is the d_{50} correlated to the dry matter per sampler?
2. What is the impact of dredging on different soil conditions on the sampler results?

Soil conditions (nr of samples)	Dry matter [kg/m ³]		d_{50} values [μm]	
	Mean values	Standard deviations	Mean values	Standard deviations
Sand (280)				
Aft (70)	50	31	75	54
Side (49)	52	32	80	80
Front (88)	55	34	84	61
Centre (74)	37	17	54	47
Silt (130)				
Aft (32)	299	90	18	14
Side (24)	285	80	26	26
Front (39)	303	80	24	23
Centre (34)	233	76	19	16
Mixed (54)				
Aft (12)	123	85	128	22
Side (12)	135	90	139	61
Front (18)	144	100	123	37
Centre (12)	73	49	81	34

Table 10-5, results second phase analyses, step 2.

10.3.2.1 The samplers

The mean values of the dry matter obtained by the Bottle sampler during all trips is significantly lower than the mean values captured by the Flow-through samplers. Focussing on the d_{50} values, similar trends are obtained, only when dredging silt different relations are shown. It is clearly shown that when dredging silt the Bottle-sampler measured about the same d_{50} values as the Aft-sampler did. The high values of the Side and Front samplers are mainly caused by 2 statistical outliers during silt-trip no 10.

10.3.2.1.1 Flow-through samplers average dry matter contents

Focussing on the dry matter values captured by the Flow-through samplers during dredging sand, the Front-sampler shows the largest values. However these differences are not significant and consequently no further research is performed. When dredging silt, the maximum of the differences between the maximum and minimum dry matter values is about 6 percent. Obviously the variations when dredging sand are larger, they appeared to be about 11 percent. The silt track showed up the largest variations in mean values, about 17 percent.

10.3.2.1.2 Flow-through samplers average d_{50} values

The d_{50} values captured by the Flow-through samplers while dredging sand show about the same consistent values as shown by the concentrations. However the d_{50} values obtained during silt trips are sometimes influenced by the appearance of sand grains, causing variations in the mean values.

During sand dredging the mean d_{50} appeared to be quite constant however the standard deviations differ significant (Table 10-5). Figure 10-8 illustrates impacts of variations in these standard deviations. The mean values of the datasets 1 and 2 appeared to be the same. However, because of variations in the standard deviations the two datasets do not cover the same area. The two data sets are based on significantly different distributions of the sampler values.

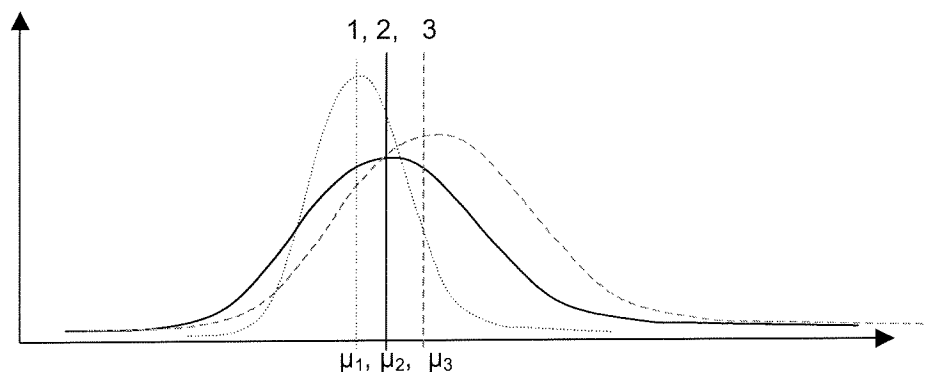


Figure 10-8, mean values and standard deviations

10.3.2.1.3 The Bottle sampler

The average dry matters captured by the Bottle sampler are significantly less compared to the Flow-through samplers, variations of up to 50 % are displayed. It appeared that the differences between the Flow-through samplers and the Bottle samplers are less when dredging silt. Only the d_{50} values while dredging silt seems to be similar to the Flow-through samplers. Compared to the Flow-through samplers the Bottle sampler samples do not show significantly different standard deviations.

Because of the quite consistence average trip-results taken by the Flow-through samplers, and because of the fact that no specific relations were found between the different positions of the Flow through samplers, it might be possible to reduce the

amount of samplers. If the sampling rate of the individual could be increased, the average results per trip will not significantly change comparing to the average results obtained by 3 Flow-through samplers together. Because of practical problems the sampling rate will decrease (about 30%), however this will not have a significant impact on the average results per trip. Nevertheless more research is needed to justify this judgement.

10.3.2.2 Time dependent analysis

Besides the combined analysis as described in this section the set up of a time depended statistical analysis was considered. The idea of this analysis was to determine the statistical numbers for certain periods of time during the overflow process. After some pilot computations it was decided not to perform this method of analysis for the following reasons:

- In the initial phase of the sand dredging process only fine silt ($<63\ \mu\text{m}$) is discharged by the overflow. In the time depended analysis this specific period should be investigated more extensively. However, the same grain sizes are obtained during the entire overflow period when dredging in silt soils. Since these trips are already analysed, this time depended analyse in this specific period will not provide additional valuable conclusions.
- The second phase in the time depended analysis should start just after the overflow is adjusted, this period will end for example 12 minutes after the overflow starts flowing. Reviewing the physical results of the samples it is shown that in this period the weir level was changed on an irregular basis.

Taking these facts into account, the time depended analyses will not lead to a better understanding of the overflow process.

10.3.3 Conclusions on the second phase analysis

In the beginning of this paragraph several questions to be investigated were stated. It appeared that answer to the question: how many Flow-through samplers are required to measure the consistence of the overflow current in a reliable way, depends on the following parameters:

- The soil conditions of the intake areas
- The parameters to be measured
- The required accuracy

There are obviously more parameters, which do influence the consistency of the overflow, however their influence was not revealed by this specific analysis because these parameters were not taken into account.

From the second phase analysis conclusions can be drawn regarding to the consistency of the measured results.

1. Reviewing the mean dry matter contents captured by the Bottle and Flow-through samplers in sand, silt and mixed soil conditions. The Bottle samples

shows always significant lower dry matter contents compared to the Flow through samples.

2. Reviewing the mean d_{50} values on sand and mixed soil conditions the same trend as in (1) is observed. When dredging in silt soils only the Bottle sampler results seems to be similar to the Flow through samples. It is noted that the standard deviations of the d_{50} values are differ significant.
3. **When dredging silt**, all Flow through samplers show about the same average dry matter content, because also the standard deviations appeared to be the same order magnitude, these values can also be established by using one Flow through sampler only.
4. **When dredging silt**, no specific distinction can be made between the average d_{50} values obtained by the Bottle sampler and the Flow-through samplers. This is probably caused by the homogeneity of the silt mixture at the overflow.
5. **When dredging sand**, all Flow through samplers show about the same average dry matter content, because also the standard deviations appeared to be the same order magnitude, these values can also be established by using one Flow through sampler only.
6. **When dredging sand**, the mean d_{50} values measured by one Flow-through sampler, seems to be rather difficult. The variations in the results per trip are significant, resulting in variations of the standard deviations (see Table 10-5).
7. When dredging in mixed soil conditions, the same conclusions can be drawn as (5) and (6).

10.3.4 Recommendations on the second phase analysis

1. It is suggested to increase the sampling rate of the individual samplers. Increasing the sampling rate should give us a better understanding of the stochastic variations per sampler.
2. If decided to sample with only one Flow-through sampler, the sampling rate can easily being increased by using the sampler bodies of the other overflow samplers (paragraph 3.2.2.1).

11 Physical analyses of measurements

Our main interest in performing this thesis is to find out if the overflow can be sampled representatively either using Flow-through or Bottle samplers. In order to validate the sampling techniques the obtained results were evaluated in a qualitative and quantitative way. However, the quantitative analyses have not helpful answers to this validation. Therefore only the qualitative analysis is left to validate the sampling techniques.

As shown in Figure 11-1 the two main mechanisms that influence the overflow current are the hopper trap efficiency and the incoming flow conditions. In this chapter the influence of these mechanisms on the overflow current consistency will be reviewed in a qualitative way. As shown also in Figure 11-1 most mechanisms of a lower order can be related to these two main mechanisms. However because of the fact that not all these lower order mechanisms seems to have a significant impact on the main mechanisms, not all will be reviewed in this chapter

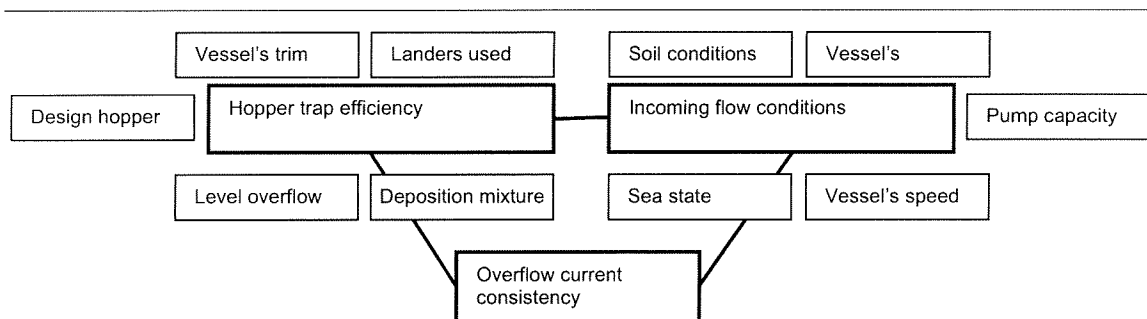


Figure 11-1, main mechanisms that influence the overflow measurements.

11.1 Incoming flow conditions

The incoming flow conditions are characterized by the particle size distributions (PSD) and density of the upcoming mixture in the suction pipes. These two parameters depend on the soil conditions, the vessels characteristics, the sea state and the used equipment (Figure 11-1). Of course more processes exert influence on the incoming flow conditions, however these fall beyond the scope of this thesis.

As stated, relations exist between the incoming flow conditions and the flow conditions at the overflow. The research on the impact of inflow variations on the overflow measurements is divided into two. First the impact of variations of the incoming concentration and velocities of 13 tracks is reviewed. In paragraph 11.1.2 the focus will be on the grain sizes discharged by the overflow.

11.1.1 The impact of incoming velocities and concentrations on the overflow

Figure 11-1 shows the measured incoming flow characteristics and the d_{50} and concentrations measured at the overflow. The variations in the incoming characteristics are not clearly shown by this figure. Reviewing 13 trips, there is only one clear example available of a sudden drop in concentrations and discharges of the incoming mixture. During dredging sand (trip 14-115), the vessel had to turn frequently to stay in the dredging area (Appendix 4). During one of these turns both suction pipes were lifted, resulting in a sudden drop in concentrations and velocities. These drops were recorded by the TDS system. Focussing on the output signal of the TDS system, Figure 11-2 shows that first the starboard side pipe was lifted, initially resulting in a decrease of density and an increase of velocity. Secondly the suction pipe on the portside was lifted, the results show that the pump on this side was already switched off. The impact of these drops is also shown by the samples taken at the overflow.

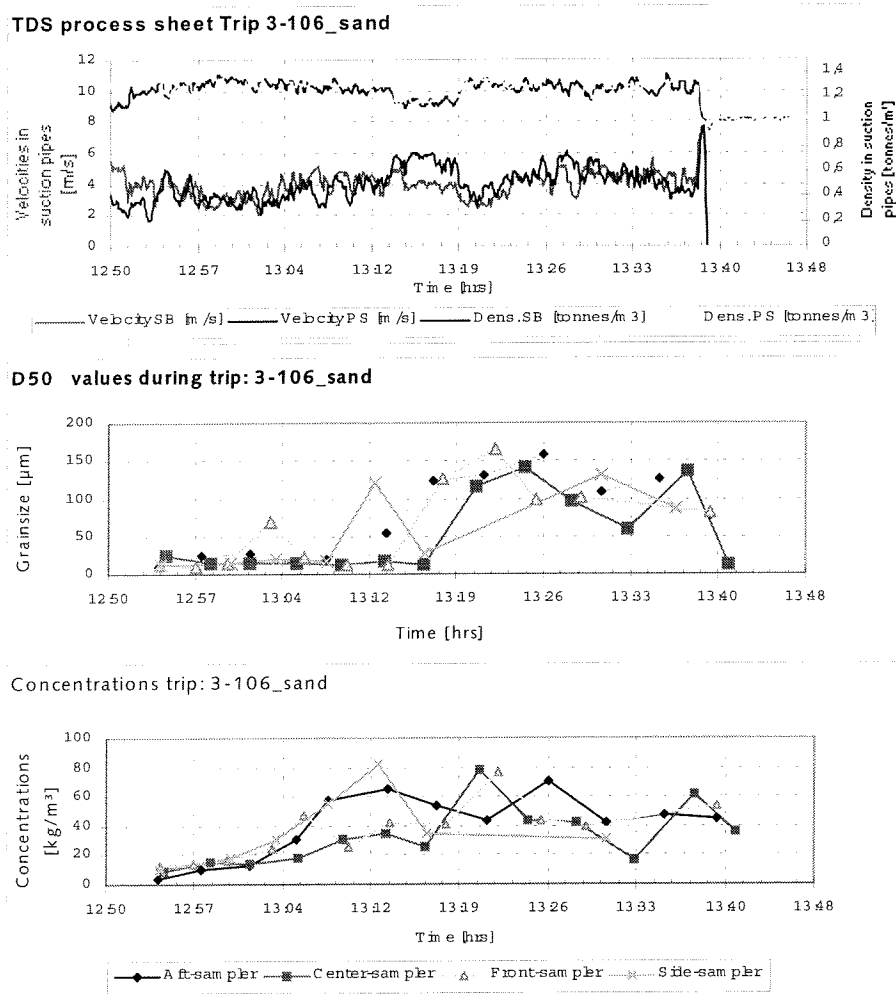


Figure 11-2, example constant inflow.

Both concentrations and d_{50} values display a drop in value, after this drop both sampling methods measured about the same values. Apparently because of a decrease in current velocity at the overflow, less coarse material was discharged through the overflow, resulting in bigger particles setting in the hopper. As already noticed in chapter 9.3 when concentrations decreases, both Bottle and Flow through samplers obtained about the same values.

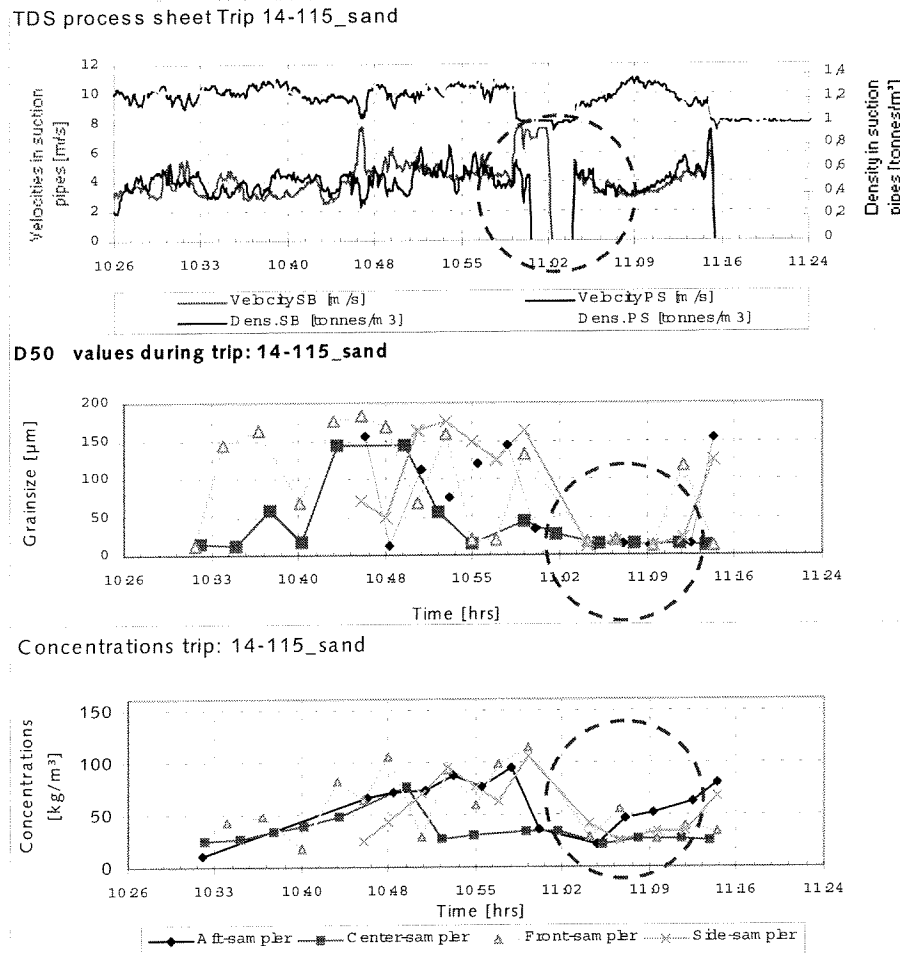


Figure 11-3, influence of variations in the incoming mixture.

11.1.1.1 Conclusions

The incoming velocities and concentrations have been reviewed for 13 tracks. It appeared that for only one track the pumps were switched off during a turning manoeuvre (track 14-115). Evaluating the measurements of the overflow current, it is clearly shown that these variations exert their influence on the overflow current consistency: the reduction of incoming velocity and concentration resulted in a decrease in concentrations and d_{50} values obtained by both Bottle and Flow through samplers.

11.1.2 The overflow current consistency, combined analysis

In the previous paragraph impact of the significant discharge variations in the suction pipes on the overflow current is reviewed briefly. Now we will focus on the grain size distributions of the incoming- and overflow mixture.

The incoming grain sizes depend on the pump characteristics and the soil conditions at the dredging area. Because of the fact the vessel moves while dredging and the soil conditions not uniform, the Particle Size Distribution (PSD) of the sucked mixture changes rapidly. It is therefore difficult to establish one representative PSD, which can be used for the incoming particle sizes. Reviewing all dredging areas of the campaign area, only the samples taken in sandpit 6 and 5 (except for a couple of rather fine samples) shows up spatially quite homogeneous PSD's. The trip performed at sandpit 6 was randomly chosen to analyse the amounts of the different particle sizes sucked and released by the overflow (Figure 11-4, step, 1, 2, 3.), the results of this analyses are stated paragraph 11.1.2.2. Because of the inhomogeneous soil conditions of the remaining trips, the second part of this paragraph (11.1.2.3) will only analyse the particle sizes of the overflow mixture in time (Figure 11-4, step, 2, 3.).

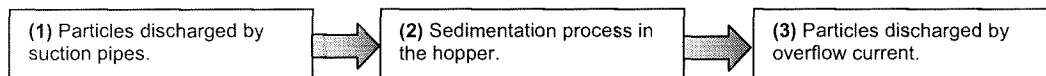


Figure 11-4, the basic dredging processes.

The reader should again notice that the purpose of this specific research is to validate the results in a qualitative way. Therefore we will investigate if the results obtained by the samplers match the trends that we expect to find. In order to explain the expectations, some theory of the hopper sedimentation models will be taken into account as well.

11.1.2.1 Set up of combined analysis

Figure 11-5 shows us again the key processes related to the dredging sequence; however now the data needed for this particularly set up of the balance is stated.

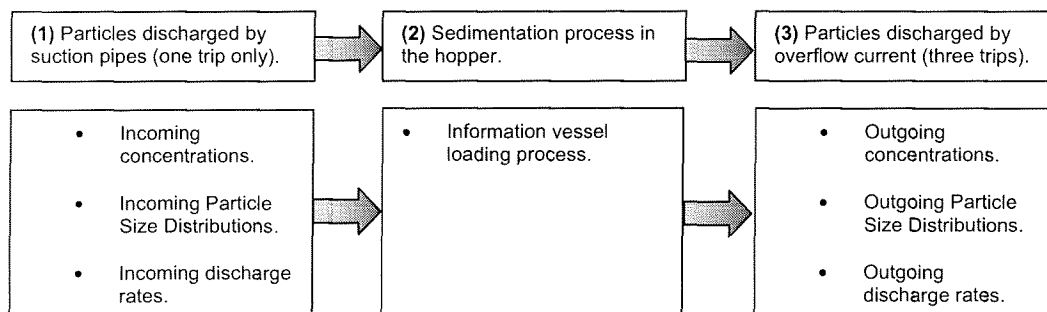


Figure 11-5, information needed for set up combined analyses

Sand trip-105 was the trip performed on the homogeneous sand soils at sandpit 6 (Appendix 11). Because of these specific conditions, it is assumed to be reasonable to

average the PSD of the seabed samples in this area to provide a single representative PSD.

The incoming concentrations and flow rates have to be known in order to compute the amounts of the different grain sizes discharged by the suction pipes into the hopper. The concentrations and flow rates have been derived from the contractor's TDS dataset (chapter 7).

The concentrations at the overflow are measured by the samplers, however the discharge rates are obtained from TDS balance (chapter 8). So both overflow sampling data and the data derived from the TDS system are required to perform these computations.

Focussing on sampling the overflow, the data of the Front Flow-through sampler are used as representative values for the overflow samples. The reason for taking only these data into account is the consistent results of the statistical analysis (chapter 10.3). Because of the largest number of samples was taken by the Front sampler the results of this sampler were used as input for this specific balance set up.

11.1.2.1.1 Procedure followed to obtain the amounts of incoming particle sizes

1. After selection of the dredging area with the most homogeneous soil conditions compute the average PSD of all soil samples (only done for trip 105).
2. Select the corresponding TDS data set of the track sailed in the corresponding area.
3. Extract from this corresponding TDS data set the:
 - Velocities in time for the Portside and the Starboard side suction pipes.
 - Densities in time for the Portside and the Starboard side suction pipes.
4. To avoid rapid fluctuations of the measuring signal, compute for every 2 minutes the average values of the concentration and velocity values for 30 seconds.
5. Taking the previous computed averages, determine for every 2 minutes the TDS [tonnes] per second dry matter by using the following equation:

$$\overline{TDS_{s2}}[t/s] = \sum_{t=t_k}^{t=t_{ss}} \rho_g \left(\overline{C_{vg}} \times \overline{Q_{s1,SB}} + \overline{C_{vg}} \times \overline{Q_{s1,PS}} \right)$$

Equation 11-1, the average TDS/s released during 30 seconds

In which: $\overline{C_{vg1,PS}} = \frac{\overline{\rho_{s1,PS}} - \rho_w}{\rho_g - \rho_w}$ and $\overline{C_{vg1,SB}} = \frac{\overline{\rho_{s1,SB}} - \rho_w}{\rho_g - \rho_w}$

C_{vg} [%], percentage of grains of the total mixture

Q_{s1} [m³/s], discharge rate of one suction pipe (SB or PS)

ρ_{s1} [tonnes/m³], specific wet density of mixture

6. Divide the averaged PSD into particular size groups, dividing the whole incoming PSD range into 7 groups is for instance a approximation
7. Multiply every 2 minutes the TDS/s with the corresponding percentage of each group (obtained from (6)).

8. Plot for every sampling point in time the amount of soil discharged by the suction pipes.

11.1.2.1.2 Procedures followed to obtain the outgoing particle sizes

The computation procedures is performed as follows:

1. Select the specific overflow-data (concentrations and PSD's) of the corresponding trip.
2. Determine per sampler the dry matter [kg/m³] and PSD's in time.
3. Divide the Particle Size Distribution of every sample into 4 size groups (0-63, 63-125, 125-177 and 177-up µm), because many PSD's are involved establishing this computation, more groups will not contribute to a better understanding.
4. Compute the overflow discharge by using the volume balance of the vessel (chapter 8)
5. Compute the TDS's discharged by the overflow by using Equation 11-2.

$$\overline{TDS}_{overflow} [t/s] = (C_{overflow} \times \overline{Q}_{overflow})$$

Equation 11-2, the average TDS/s at the overflow.

In which: $C_{overflow}$ [tonnes/m³], the dry matter content
 $Q_{overflow}$ [m³/s], discharge rate at the overflow

6. Compute the TDS's per particle size group by multiplying the TDS with the corresponding percentage of every group.
7. Plot for every sampling point in time the amount of soil discharged by the overflow pipes.

The results of these computation are presented in appendix 11.

11.1.2.2 Results combined analyses

The results of the incoming and outgoing PSD's computations of sand trip 105 are shown in Figure 11-6. The figure of the incoming PSD's displays that the highest contribution to particles discharged in the hopper is given by the particle range 125-177 µm.

One should notice that the upper graph of Figure 11-6 is based on one PSD resulting is the different groups being distributed equally in time. Only the concentration and velocity parameters vary during the dredging process. These parameters are therefore responsible for the increasing trend of all groups during dredging process. The most likely explanation for this trend is probably due to an increase of the pump efficiency due to the increase of the vessels draught and the related total suction head.

As the overflow of trip 105 concerns (Figure 11-6), it is noticed that a larger amount of grain sizes between 0 and 0.63 µm was discharged by the overflow than that was discharged into the hopper. This physical impossibility can be explained by the fact the average soil condition PSD did not represent the actual soil conditions.

Even with a quite homogeneous bottom composition as in this trip, no useful relation between incoming and overflowing PSD is found. Combined with the uncertainties

regarding the incoming averaged sea bottom PSD as seen in other areas, the combined analysis will not produce useful results for this stud. Therefore we will focus in the next paragraph on the overflow particles sizes distributions only.

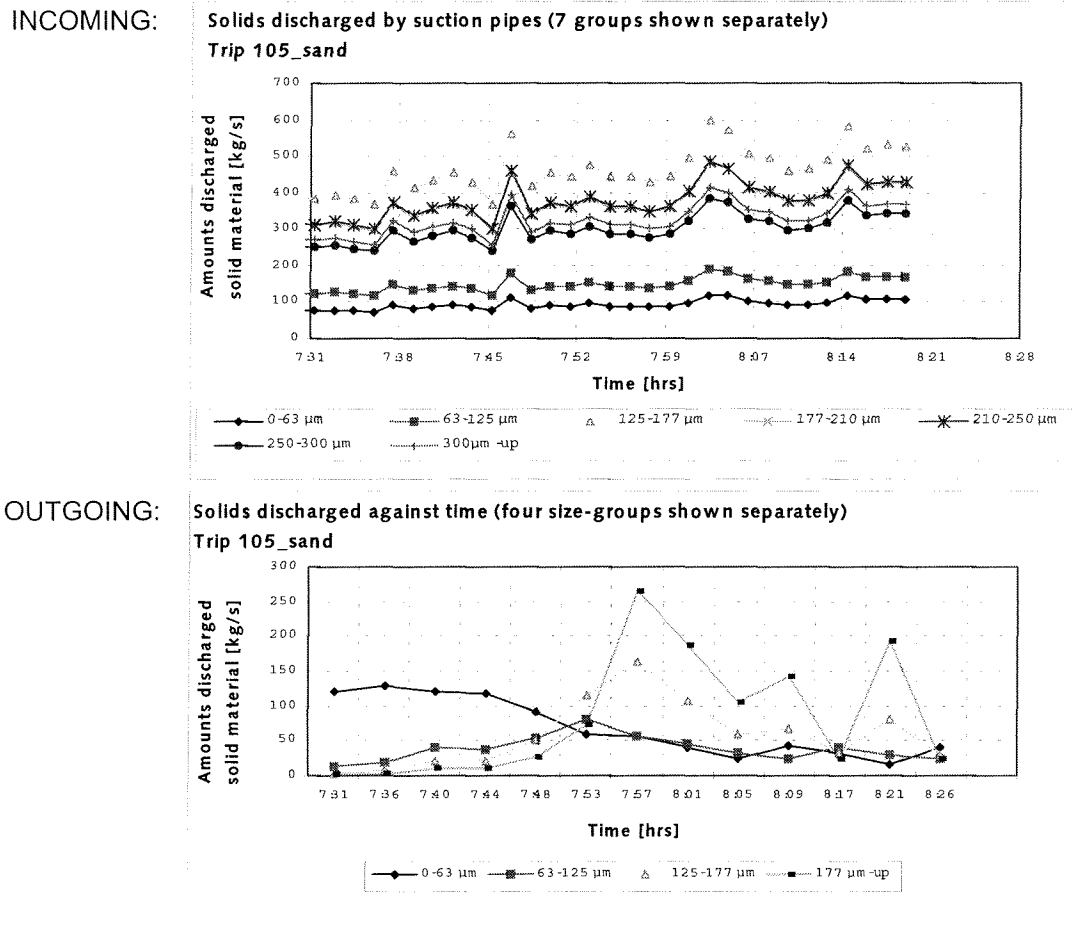


Figure 11-6, the solids discharged in the hopper and over the overflow.

11.1.2.3 The outgoing Particle Size Distribution further researched

The amount of sediment released by the overflow was computed for four trips. The results of the overflow computations are shown in two different ways. The units at the X- and Y- axes are the same; one graph shows the four size groups separately (Figure 11-7), the other graphs show these groups cumulatively (Figure 11-8). This cumulative graph is established by summing up the different Particle Size Distribution groups per sampling point.

As stated earlier the overflow current of four trips has been researched during the overflow process. Thereby focussing on the amounts of sediment released by the overflow. Three of the four trips show up rather identical results (trip 105, 108 and 113), however one trip shows up completely different values (trip 115). In this paragraph the

results of the rather identical outcomes (trip 105, 108 and 113) will be reviewed first. The results of trip 115 will be reviewed second.

11.1.2.3.1 The results of trips 105, 108 and 113

Focussing on the sediment particles released by the overflow for the four particular trips, two main phases can be distinguished. During the first phase of about 15 minutes the fine particles dominate ($< 0.63 \mu\text{m}$).

The lines presenting the appearance of different grain sizes show fairly smooth transitions (see Figure 11-7 and Figure 11-8). The coarse material is not present, but starts moving at the end of this period. During this first phase the amounts shown by the line representing the fine grain sizes tend to tail off or stay constant to a certain level. At the start of the second phase coarser grain sizes even larger than $200 \mu\text{m}$ are already present. The subsequent measured values are highly irregular. However they stay within a certain bandwidth of $500 \mu\text{m}$.

The results of trips 108 and 113 are presented in appendix 11. Both graphs show also the initial phase, dominated by fine grain sizes and the absence of coarse material. After 10 to 15 minutes the coarse material comes in suspension as well and is discharged by the overflow.

11.1.2.3.2 Interpretation results of trips 105, 108 and 113

By explaining the results of this specific analysis again we first focus on the initial 15 minutes of the overflow process.

The processes in the hopper can explain the presence of large amounts of fines in the hopper in the initial phase of the dredging process before the overflow starts discharging the hopper mixture. In this initial loading phase, only the large grains (larger than $200 \mu\text{m}$) are fully deposited, the fines are mostly held in suspension because of turbulence and slow settling rate. When the hopper level reaches the level of the overflow, a huge amount of small particles are in suspension that will be discharged very quickly. At this moment, depending on the incoming concentration the hopper is filled with about 15 to 30 % solid material on the bottom.

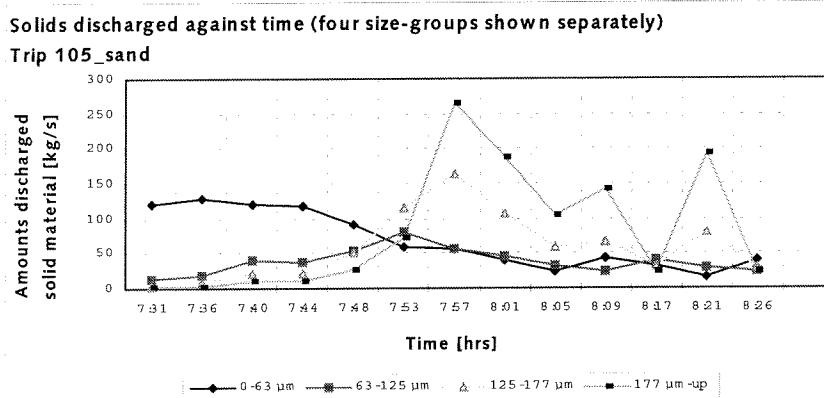


Figure 11-7, Trip 105: released solids at the overflow, four Particle Size Distribution groups shown separately.

Solids discharged against time (four size groups shown-cumulatively)
Trip 105_sand

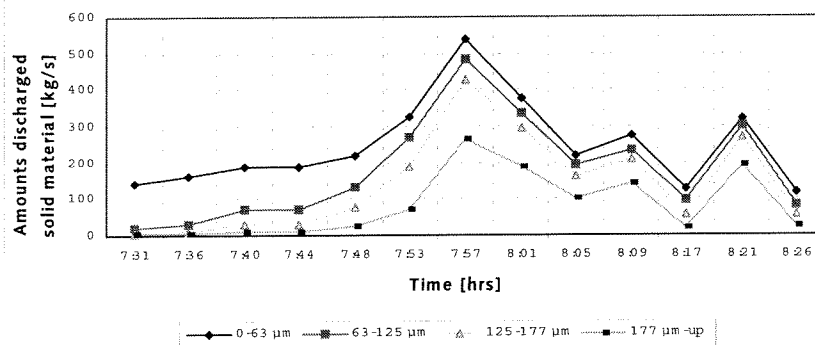


Figure 11-8, Trip 105: released solids at the overflow, four Particle Size Distribution groups shown cumulatively.

As the loading process continues, a larger part of the hopper is filled with settled sediment. Consequently a smaller part is available for all transport processes, resulting in an increase in velocities and turbulence and a lower settling rate of courser grains. The variations in the level of the weir seem not to have any influence on the results so far. Consequently another mechanism causes the fluctuations in the results.

11.1.2.3.3 The results of trip 115

As already stated trip 115 showed up completely different values. Figure 11-9 and Figure 11-10 show the results of this trip. Again Figure 11-9 shows the amounts of solids discharged against time for the size groups separately, Figure 11-10 shows the same results accumulated per sampling point.

Solids discharged against time (four size-groups shown separately)
Trip: 115_sand

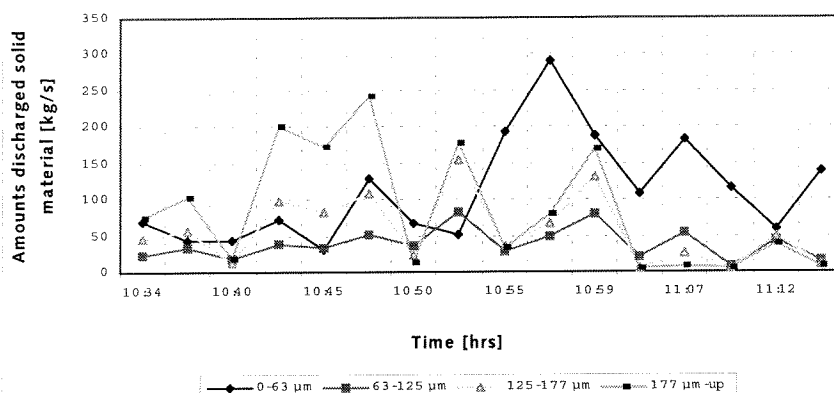


Figure 11-9, Trip 115: released solids at the overflow, four Particle Size Distribution groups shown cumulatively.

In the initial phase of the dredging process no smooth transition zone is present as shown by the other graphs. The particle sizes of all groups are in suspension and

discharged by the overflow current. At the end of the trip there is a slight decrease in the amount of coarse grains discharged, however small particles are still present.

Solids discharged against time (four size-groups shown cumulatively)
Trip 115_sand

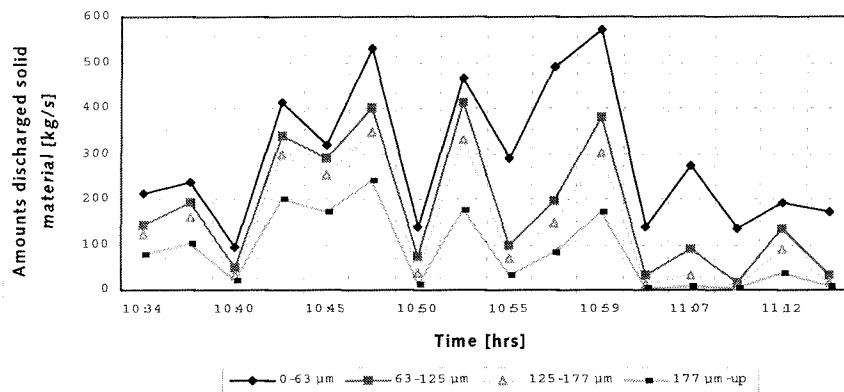


Figure 11-10, Trip 115: released solids at the overflow, four Particle Size Distribution groups shown cumulatively.

11.1.2.3.4 The interpretation of results trip 115

The explanation for these results must differ from the explanation for the results of the other three trips. The presence of turbulent currents is the most likely explanation for the irregularities that are displayed in the results shown above. It was already explained by the increase of the level of solids in the hopper that turbulent currents were present. However during trip 115 corresponding with a higher level of turbulence results were already obtained in the initial phase of trip.

Trip ID	Time	Comments bridge observer reports
105_sand	7:45	Pumps were reduced to 80% due to boiling water problem
108_sand	13:53	Portside central lander is opened to try to make the vessel list to portside so that air bubbles move to Starboard side.
	14:03	Lander is closed
113_sand	Start	Large plume, just after start of dredging, possible from mud in hopper leaking through.
	13:55	Portside lander opened for 4 minutes
115_sand	Start	All landers opened
	10:49	Central lander was closed.

Table 11-1, comments on use of landers from bridge observer reports.

It appeared that only in this trip the hopper was filled using also landers closer tot the position of the overflow. This will result in a higher level of turbulence close to the overflow and provide an explanation for the different results of this trip. In Table 11-2, the comments relating to the use of the landers is shown. Indeed this table shows valuable input in explaining the exceptional results of trip 115. In the initial phase of the dredging process it appeared that all landers were used. During the other three trips the use of all landers together was not noticed. By using all landers the mixture sucked by the suction pipes is discharged at several places into the hopper (instead of the back of

the of the hopper). The increased level of turbulence and a shorter travelling distance to the overflow seems to result in a decrease of the hopper trap efficiency.

One should bear in mind that by postulating the theory in explaining the results of the measurement it is not said that this theory is right. The theory is based on the interpretations of the writer and alternative or additional explanations may be possible. It is therefore recommended to analyse the remaining 10 trips as well.

11.1.2.4 Conclusions on the outgoing Particle Size Distributions

One should notice that the conclusions stated below are based on four trips and the interpretation of the writer of this report. To make these conclusions really reliable one should analyse many more trips.

1. When using the lander at the aft of the vessel only, the particles sizes between 0-63 μm stay in suspension during the initial phase of the dredging process, only these specific particle sizes were measured at the overflow (11.1.2.3).
2. When all landers used, all grain size groups stayed in suspension already in the initial phase of the dredging process. This caused by the reduced retention times and turbulence all over the hopper.
3. In course of the dredging process the discharged solids measured become more irregular. Most probable the rising level of solid material in the hopper resulting in an increasing level of turbulence above the solid material, triggers these irregularities.
4. The impact of significant reductions of the incoming velocities and concentrations is clearly shown in reductions of the outgoing amounts of solids.

11.1.2.5 Recommendations on the outgoing Particle Size Distributions

- From the statistical analyses (chapter 10) it appeared that the measuring results of the Flow through samplers were quite the same. In future research one should therefore try to use the results of the Flow through samplers in the set up of this analysis, instead of the results of the Front-Flow-through sampler only.
- During this analysis the overflow discharge was considered to be constant. However in reality it is not. The reason for keeping these values constant was the fact that the order of magnitude of these variations was too small to pick these up from the balance output graphs (appendix 9.1 and 9.2). In future research one should try to bring these variations into account in the set up of analyses.
- It is recommended to perform this specific research also on the remaining 10 trips. Moreover, it can be useful to compare these results with the results of specific hopper sedimentation models.

11.2 Physical aspects of the TSHD itself

11.2.1 Influence of sea state on overflow measurements

Video and observer records maintained during the field trial tell us the weather conditions were stable. For detailed information about significant wave period and wave height one is referred to the weather records of the KNMI (the Dutch weather institute). Because of the calm sea it was decided not to investigate the relations between wave heights and overflow measurements.

11.2.2 Influence of vessel's trim on the overflow measurements

The influence of the vessel's trim on the measurement results has been researched for thirteen trips. For all trips it appeared that in the initial phase of the dredging process the vessels is fully trimmed backwards. During the loading process before the overflow starts discharging the dredged material the vessel trim is set to a minimum. This is for instance shown by Figure 11-11, in this graph the average front and aft draughts are plotted in time. It is clearly shown that both draughts becomes equal during the dredging process. At 13:40h when the overflow starts, the difference between both levels is about 30 cm, this corresponds with a trim angle of 0.3° (distance between depth gauges is 63 m).

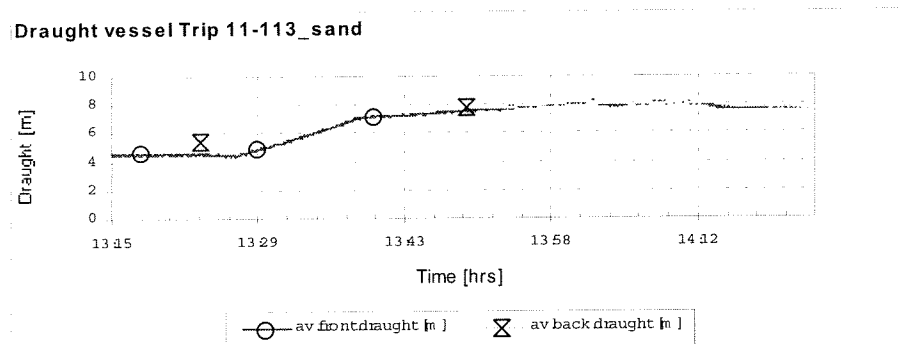


Figure 11-11, the average front and aft draughts in time.

One should notice these draughts are based on the TDS datasets of the contractor. We discovered already that scaling operations caused differences between the contractor's dataset and the dataset of the North Sea Directorate, nevertheless the quantitative use of the numbers could be justified.

Figure 11-12 show a schematic drawing of the vessel with the overflow positioned in the front of the vessel. The positions of the front and aft samplers are shown. For more detailed information about the positions of the draught sensors one is referred to appendix 7.5.

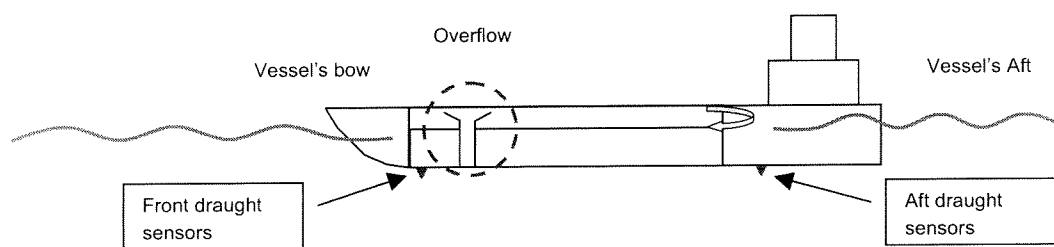


Figure 11-12, the schematic presentation of the overflow position.

To investigate the influence of the vessels trim on the overflow measurements, we have a closer look at the overflow area. Figure 11-13 shows us a simplified image of the current conditions at the overflow. In this image the overflow current while dredging sand is divided into two layers (Van Rhee 2002). The consistency of the upper layer (between the straight and dotted line) is considered to be water only; the second layer (below the dotted line) shows a higher density layer. The video records showed the presence of the less dense upper layer, however the transition zone between both layers is obviously not as abrupt as shown by Figure 11-13.

During dredging silt, the percentage of fine particles is significantly more compared to dredging sand. The appearance of this fine material results in a relatively homogeneous density profile at the overflow funnel.

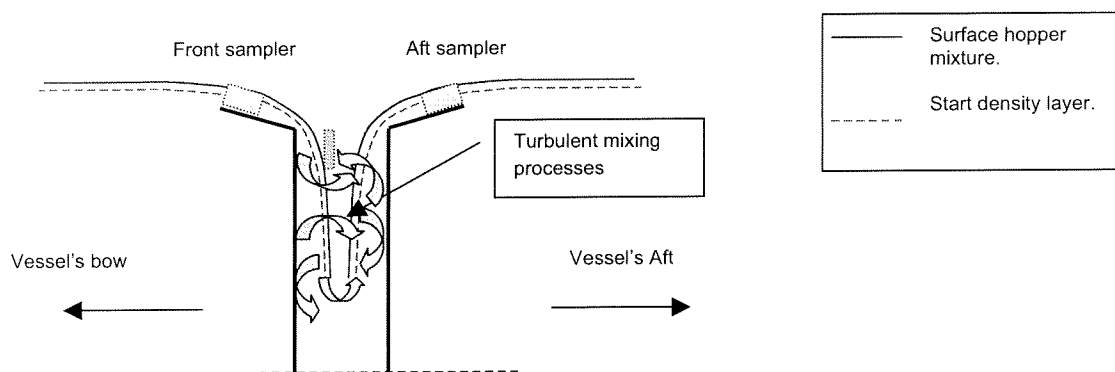


Figure 11-13, simplified image of the current conditions at the overflow (trim vessel = 0).

It is appropriate to consider that the trim of the vessel influences this current condition because the relative position of the overflow towards the current condition changes. Figure 11-14 shows the current condition when the vessel is trimmed extremely backwards. At the front side only the low-density water layer is discharged and the high-density layer is deflected.

Of course such extreme circumstances are not realistic for this particular measuring campaign, although an attempt has been made to draw up a relation between the trim of the vessel and the results obtained by the front and aft samplers.

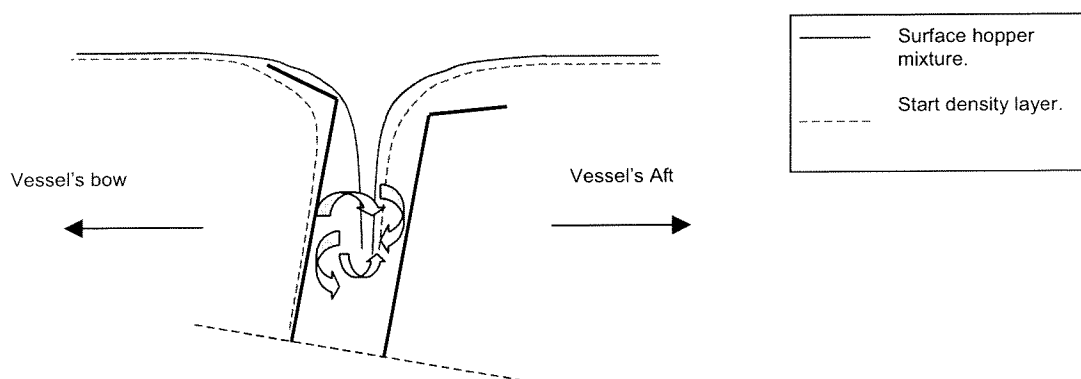


Figure 11-14, simplified image of the current conditions at the overflow (the vessel is trimmed backwards).

During this attempt the d_{50} , d_{10} and concentration values of the samples were related to the trim of the vessel. Although expected, no specific trends were obtained, probably the small trim angles prevented any relationship being derived between the outcomes of these measurements and the trim of the vessel.

11.2.3 The influences of overflow level adjustments on the measurements

In the course of the dredging process dredging sand and silt (on behalf of the field trial) the overflow is lowered several times to release the low-density surface water from the hopper.

By adjusting the overflow level downwards, the discharge at the overflow increases. However, after a few minutes, a new equilibrium situation is attained where the outgoing discharge rate is about the same as the incoming discharge rate. The volume balances in appendix 9.1 and 9.2 show this increase-decrease and stabilisation of the overflow currents for all trips performed during the field trial.

The influence of the overflow level adjustments was already reviewed in chapter 9.2.1. In that chapter a clear distinction was made between the steady state situations and the period just after the first adjustments of the overflow level, however no specific trend could be discovered. In this chapter again the impact of the overflow level variations on the measurements is reviewed, again no specific relations between the adjustments and the measurements are obtained.

11.2.4 The relations between computed and measured released TDS's

The method of TDS release computations by using the sediment balance has been explained in chapter 8. The sensitivity of the computations was reviewed at the end of that chapter. It was concluded that the TDS computations were very sensitive for small variations of the input values, resulting in quite unreliable outcomes (chapter 8.5). In contrast, the set up of the volume balance appeared to be quite reliable. From this volume balance the discharge of the hopper mixture at the overflow is derived. These volume values are used in further analyses, however the results of the TDS-release computations were not incorporated in any analysis. In this paragraph a final attempt will be made by investigating if these computations show any trends with the measured

values at the overflow. Thereby we will focus the released concentrations in the steady state situation. In brief the following set up is used.

11.2.4.1 Input for comparison

1. The results of the overflow measurements. However for this specific comparison, the concentrations obtained by the Aft-sampler was used.
2. The average discharge at the overflow in steady state situation.
3. Duration of the steady state situation.
4. The specific densities of the grains and process water.

11.2.4.2 Assumptions

1. A homogeneous mixture at the overflow
2. A constant overflow discharge during the steady state situation
3. Constant concentrations during steady state situation

Computations and output:

1. Determine the volume percentage of grains in the mixture, based on the average concentrations obtained by the Aft-sampler
2. Determine the TDS/m³ that is discharged by the overflow
3. Determine the cumulative amounts of TDS discharged in the steady state situation.

Track ID	TDS losses computed [tonnes].	TDS losses measured, combined with computed discharges	Delta measured vs. computed.
1-105	477	200	+277
3-106	150	91	+163
6-108	0	585	- 585
8-112	679	132	+547
11-113	0	198	- 198
14-115	472	300	+172

Table 11-2, TDS values computed vs. measured values during dredging sand (Aft sampler).

The output of these computations is presented in two tables, Table 11-2 shows the results of dredging in sandy soils and Table 11-3 shows the results while dredging silt. As we already expected, no specific relations or trends are obtained. The TDS balance computation can be identified as the main reason for this specific mismatch, therefore one should not pay too much attention to the results derived from track 9-23. As shown in Table 11-3, about identical measured and computed TDS values were obtained during this trip.

Track ID	TDS losses computed [tonnes]	TDS losses measured, combined with computed discharges.	Delta measured, vs. computed.
2-8	2163	1842	321
4-107	2967	1641	1326
5-15	No TDS data available	-	-
7-16	1306	1468	-162
9-23	985	1006	-21
10-24	2351	2592	-241
12-29	1205	1173	32
13-30	1135	748	-387

Table 11-3, TDS values computed vs. measured values during dredging silt (Aft sampler).

11.2.4.3 Conclusions

1. The influence of the vessels trim appeared to have no impact on the overflow measurements.
2. The sediment balance based on TDS-system data while dredging sand cannot be use for the validation of the sampler techniques.
3. The overflow losses computed by qualitative TDS balance are more accurate when dredging silt than when dredging sand. Nevertheless these results are still not usable for any validation of the overflow samplers.
4. Reviewing the results by taking the level of the weir into account, it appeared that there was no direct relation between the weir level and the discharged solids measured.

11.3 Sampling by Bottle sampler

From the statistical analyses it appeared that when sand dredging, the results obtained by the Bottle sampler often diverge significantly from the results obtained by the Flow-through samplers. Both concentrations and the particle sizes obtained by the Bottle sampler show lower values than those captured by the Flow-through samplers (chapter 9.2 and 10.3.2). In this paragraph we will go into the physical explanations of these significant trend.

Both samplers will be reviewed on their sampling technique and the position of the sampler, when taking the sample. These two aspects are considered to have significant influence on the sample. One should notice that the clarification for some results is based on the interpretation of the writer of this thesis report.

Focussing on the Bottle sampling technique, the top of the sampler was at a sampling depth of about the height of the sampler itself below the mixture surface (about 30 cm). One person operated the sampler. During sampling the operator tried to move the sampler as much as possible to the centre of the overflow (chapter 3, Sampling the overflow). When the sampler was in position, the lid of the sampler was lifted for a few seconds and the sampler was filled by the overflow mixture. Preferably the opening time should be only as long as is needed to fill the bottle. In practise it could not be determined when the bottle was filled completely. The opening time of the lid was a choice of the operator. After closing the lid the sampler was pulled back on the operation platform.

As stated, it is assumed that the lid opened for a longer period than necessary, because mostly the bottle was filled completely when recovered. According to [Van Rijn & Schaafsma 1986, London] during the period when the lid of the sampler was open when the bottle was already full, fine grains ($< 100 \mu\text{m}$) are washed out from the Bottle sampler with the result that the sample will be coarser than it should be.

However the measurements as performed during the field trial with the Cornelia show the opposite, the Bottle samples contained finer material than the Flow-through samples.

Figure 11-15 shows a sketch of the overflow with the Bottle sampler hanging in the centre. It is assumed that especially during dredging sand a concentration, velocity and Particle Size Distribution gradient is present from the top to bottom of the overflowing layer [Van Rhee 2002]. In the vertical overflow pipe itself turbulent processes are present resulting in mixing of layers with different compositions. When the overflow-mixture is moving from the overflow funnel down the pipe the concentration profile is expected to change into a more homogeneous mixture. However we do not know if or where complete mixing will occur. It is possible that the overflow pipe is not long enough to get a totally homogeneous concentration profile.

The mixing length L (Figure 11-15) is defined as the distance needed to obtain a totally homogeneous mixture. As stated, it is not known how long this mixing length is. Turbulent diffusion computations should increase our understanding of this particular phenomenon.

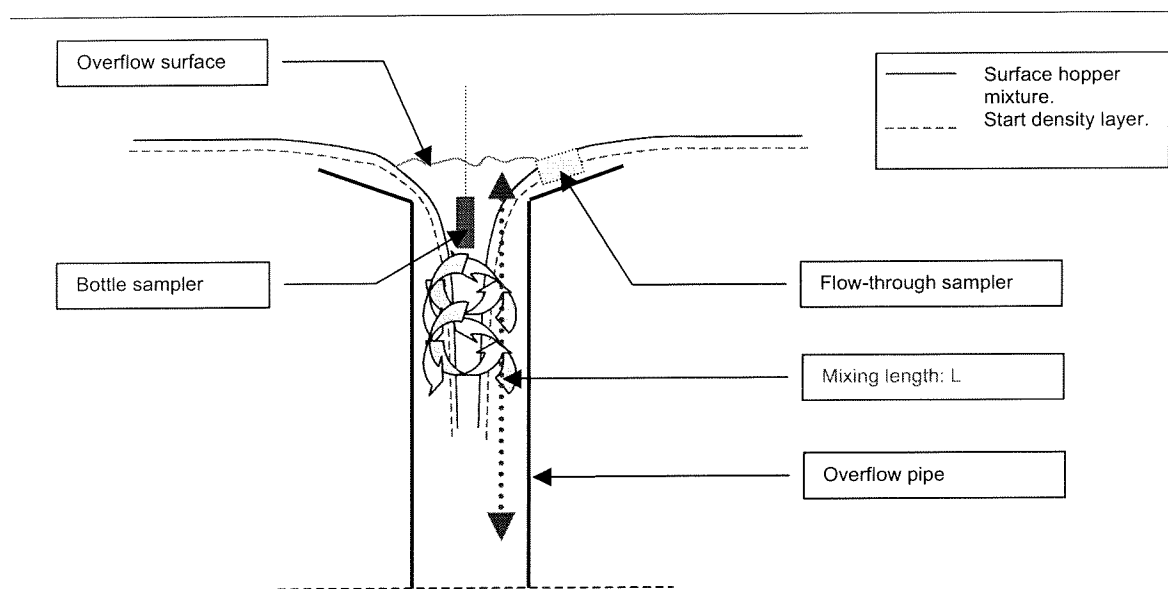


Figure 11-15, Principle sketch of sampling the overflow by Bottle sampler.

11.3.1 Conclusions on sampling by Bottle sampler

When taking the previously stated explanations of the flow conditions into account when sand dredging there is a possible explanation of the variations in the sampling results of the different sampling techniques.

The Bottle samples were taken at the near surface of the overflow current. At this location the mixing length is very small and therefore still a gradient layer is present. At the top centre of the overflow a mixture is present which lower concentrations and fine grains. The Bottle sampler was positioned in this area which can explain why the Bottle sampler indeed captured less dry matter and smaller grain sizes than the samples taken by the Flow through samplers.

11.3.2 Recommendations on sampling by Bottle sampler

To prove the theory as stated above, during next field trials one should sample the overflow by using Bottle samplers at different depths in the overflow at the same time:

1. At the end of the overflow pipe, just above the vessel's hull.
2. In the pipe, one or two meters below the funnel.

12 Conclusions and Recommendations

In this thesis the results of sampling the overflow from a Trailing Suction Hopper Dredgers (TSHD) were studied. Besides the overflow samples itself, the related processes on board of the TSHD were reviewed in order to identify the processes which influence the overflow consistency. The main conclusions of this study are presented in this chapter. First the research objectives are answered; second the general conclusions are stated per subject. Moreover recommendations are drawn, which may be useful for future field trials.

12.1 Answering the research objectives

Main question

Can the Particle Size Distribution and the solids concentration leaving the dredging vessel during dredging operations be calculated sufficiently accurately from parameters measured in overflow samples and the monitored data of the TSHD processes?

Answer on the main question

The amounts of particles discharged by the overflow during one trip can be calculated by the parameters obtained from the samples taken at the overflow. The accuracy of these computations is not known exactly, however it is estimated to be average of 25%.

The computation of an average Particle Size Distribution of the overflow is also possible by using the parameters obtained from overflow samples. However rather large fluctuations are found. Focussing on the fine particles like d_{10} values only, quite consistent results are obtained. This finding is encouraging since these fine particles are considered to be main contribution to the sediment plumes in the vicinity of TSHD.

1. **Q: Which sampling technique is preferred for measuring campaigns in the near future?**

A: The flow-through sampler is preferred to sample the overflow, based on:

- The consistent and reproducible results.
- A credible explanation for the difference between the results obtained using the two types of sampler. According to this explanation the Bottle sampler produces less representative results, particularly when the soil particles are large.
- Under certain conditions, when only fine particles are present, the Bottle sampler yields equally reliable results.

2. **Q: Are the TDS monitoring systems of both the contractor and the North Sea Directorate sufficient to predict the sediment concentrations leaving the TSHD during dredging, or is the overflow sampling method required?**

A: The accuracy of the TDS system is not sufficient to compute reliable sediments losses at the overflow.

3. **Q: Is it necessary to sample the overflow at more than one location and, if so, which locations are preferred?**

A: No. In this research no specific trend between sampling locations is found, the exact sampling location is not of importance.

4. **Q: What number and size of samples is the best, is it possible to reduce the sampling rate, without losing valuable information?**

A: Large fluctuations are evident in the results which indicates that a relatively large number of samples is required to establish reliable averages. Since the sample location (in this case) does not seem to make a difference, the samples can also be taken at high frequency with one sampler.

From this study, the total number of samples per trip could be reduced by approximately 30 % without affecting the reliability of the calculated average.

As to the sampler size, it is important to try to sample the full depth of the overflowing layer and have other measures sufficiently large to compensate for obstructing devices (i.e. bungees)

5. **Q: Is it possible to determine which processes on a TSHD are most important with respect to the computations of the composition of the overflow losses (sensitivity analysis)?**

A: Computation of the composition of overflow losses from recorded ship data failed, consequently no sensitivity analysis is done. However, the choice of landers does seem to have an effect on the composition of the overflow.

12.2 Conclusions on the overall research

12.2.1 The measuring campaign

1. The soil samples taken at the in-shore silt-area (Area E) of the Maasmond indicate rather homogeneous soil conditions (paragraph 4.3.2).
2. The soil samples taken in the off-shore silt-sand area (Area F) of the Maasmond become progressively coarser towards the sea.
3. With the exception of the Maasmond F-area, no spatial relations could be identified in the campaign dredging areas. For all soil sampling locations no specific relations are obtained in the sample vertical (paragraph 4.3.3).
4. Sandpit 6 (Verdiepte Loswal) and Sandpit 5, have the most homogeneous soil conditions. This makes these areas valuable for further research (paragraph 4.3.3 and 4.3.5).
5. Although some video records of the overflow sampling were made, they were not continuous and a time stamp was missing; therefore it is not possible to compare the data from the samplers with the specific current regime (paragraph 6.1).
6. It is shown by the video records that the orientation of the side sampler is not parallel to the overflow current. Also variation of this angle of flow during the overflow process is shown. Taking the aspect ratio of the samplers into account (paragraph 3.2.2), sampling by flow-through samplers is not truly iso-kinetic.

12.2.2 Overflow samples analysed

The samplers general

7. No relations could be obtained between the measurements obtained by the Bottle sampler and Flow-through sampler (paragraph 10.2.1).
8. Focussing on the correlations between the three Flow-through samplers in time and space, no clear statistical trends are obtained (paragraph 10.2.2.3).
9. The Bottle samples always shows significant lower total dry matter contents compared to the Flow-through samples in sand, silt and mixed soil conditions (chapter 9 and paragraph 10.3.2).
10. Reviewing the d_{50} values on sand and mixed soil conditions the same trend as in (9) is observed. When dredging in silt soils the Bottle sampler results seem to be similar to the flow-through sampler results. It is noted that the standard deviations of the d_{50} values differ significantly (chapter 9 and paragraph 10.3.2)..
11. When dredging silt, both methods of sampling show an increase of concentration over time. When dredging sand, the Flow-through samplers show a slight increase of concentration in time, the Bottle sampler shows this trend only for some tracks (paragraph 9.2.1).
12. When dredging sand or silt, and only small particles are present in the overflow funnel, the Bottle sampler results appeared to be similar to the Flow-through sampler results (paragraph 9.2.1 and 9.3.1).

Dredging sand

13. **When dredging sand**, all three Flow-through samplers show about the same average dry matter content and the standard deviations appeared to be of the same order of magnitude, these values can also be established by using one Flow-through sampler only (paragraph 10.3.2).
14. **When dredging sand**, the d_{50} variations in the results per trip are significant, resulting in variations of the standard deviations. (see Table 10-5).
15. **When sand dredging**, the Flow-through samplers generally show an increase of concentration in time, the Bottle sampler shows this trend only for some tracks. That makes the results of the Bottle sampler rather suspicious.
16. The d_{10} and d_{50} curves obtained from the Bottle sampler appeared to have less fluctuations compared to the d_{10} and d_{50} values obtained from the other Flow through samplers. The d_{50} values obtained by the Bottle sampler tend to be a little less comparing to the d_{50} values obtained by the Flow-through samplers.
17. The d_{10} values obtained by both sampling methods, appeared to be quite similar for almost all sand trips in the same dredging area (sandpit 6); the results of the samples obtained by the Flow-through samplers tend to be slightly (up to 3 μm) higher than the results presented by the Bottle sampler.

Dredging Silt

18. **When dredging silt**, all Flow-through samplers show about the same average dry matter content, also the standard deviations appear to be the same order magnitude, these values can also be established by using one Flow through sampler only (paragraph 10.3.2). The Bottle sampler shows significantly lower values of dry matter content compared to the Flow-through samplers.
19. **When dredging silt**, no specific distinction can be made between the average d_{10} and d_{50} values obtained by the Bottle sampler and the Flow-through samplers. This is probably caused by the homogeneity of the silt mixture at the overflow (paragraph 10.3.2). Thereby both methods show an increase of concentration over time.
20. The concentration values shown by the three Flow-through samplers appear to be consistent in time as well. Nearly all samples in the silt trips taken by the Flow-through samplers show similar concentration values. The conclusion can be drawn that the position of the Flow-through samplers on the overflow funnel seems to have no impact; this conclusion should be verified during the statistical analysis of the overflow samples (chapter 10).

Dredging mixed sand / silt

21. When dredging in mixed soil conditions, the same conclusions can be drawn as (12) and (13).

12.2.3 Physical impact on the sampling results

TDS releases computed and measured

22. It is plausible to assume the dataset of the contractor contained the same data as the dataset of North Sea Directorate. Therefore this dataset is suitable for further research: the set up of the volume and sediment balances (paragraph 7.4.1).
23. By adjusting original measured values of the velocity meters by 17 to 22% per trip and the measured densities by -1 to 4 %, it was possible to recalibrate the TDS datasets of 13 tracks in the period before the overflow was used (paragraph 7.4.2). One should be careful with this recalibration because it does not automatically mean the entire dredging sequence of the particular trip is calibrated well, because the leakage by the hopper doors is not taken into account while dredging sediment.
24. Sensitivity analyses have shown that variations in the input data of the balance causes errors which were greater than the measured TDS values at the overflow (paragraph 8.5).
25. Both quantitative and qualitative validation of the overflow samplers by comparing the measured concentrations with the TDS balance computed concentrations is not possible because of (20) (paragraph 8 and 11).

The vessel's characteristics

26. The use of the different landers significantly influences the overflow measuring results (paragraph 11.2.2)
27. The overflow level adjustments are not confirmed by the overflow measuring results paragraph 11.2.2).
28. The vessels trim appears to have no impact on the overflow measurements, no correlation was obtained (paragraph 11.2.2).

12.3 Recommendations on the overall research

12.3.1 The measuring campaign

One should note the following items during future calibrations of the TDS system.

1. Set up and make use of a proper measuring protocol.
Calibrate as much as possible:
2. Level sounders, depth gauges, velocity meters, density meters
3. Save all the numbers used during the calibration on the bridge of the vessel.
4. Only use one set of properly calibrated sensors and loggers.
5. Check the hopper level sounders manually.
6. Check the depth gauges manually.
7. Calibrate the overflow level sensor, and check if the level of the load in the hopper has approximately the same level (15 to 20 cm difference).
8. All calibration values concerning every sensor should be properly stored in one project data base.
9. Pinpoint the exact locations of the measuring sensors (velocity and density meters).
10. Quantify the effect of the vessels speed on the output of the depth sensors.
11. Determine for every soil condition the leakage by the hopper doors.
12. Log always which lander is used.
13. Check the TDS balance by pumping only water into the hopper.

12.3.2 Video monitoring

14. The sampling crew for the next measurement campaign should view the video records of the overflow sampling before the campaign.
15. At the overflow, the sampling techniques, and the installation of the four samplers was recorded. During the next field trip, a fixed camera positioned above the overflow is recommended. The camera should display a continuous time registration on the records. The camera position should be selected to avoid personnel standing in front.
16. If in the next field trial again three-Flow-through samplers will be used, it is recommended to paint the Flow through samplers in different colours, this makes it easier to identify the samplers on screen.
17. The streamlines at the overflow should be recorded by the fixed camera. Extra lights sources shining over the overflow area will improve the quality of the records.

12.3.3 Set up TDS balances

18. In this research the calibration is performed on the two suction pipes using an identical calibration coefficient. In future research the error caused by calibration of both pipes at once should be quantified.

19. During future measuring campaigns, the TDS balance should be established in real time. Errors caused by calibration and signal failures will immediately be discovered and can be solved.
20. It is worth investigating what influence the delay of the measuring signal has on the accuracy on the TDS balance. Monitoring all variations between the measured variations and the actual variations will increase the insight into the whole measuring process.
21. In future measuring campaigns the overflow levels and the levels of the mixture in the hopper should be measured accurately. With these values one can establish the overflow discharge rates by using weir-equations. Resulting into no volume is needed to compute the discharge at the overflow

12.3.4 Overflow sampling

22. It is suggested to increase the sampling rate of the individual samplers. Increasing the sampling rate should give us a better understanding of the stochastic variations of the overflow consistency.
23. If it is decided to sample with only one Flow-through sampler, the sampling rate can easily being increased by using the sampler bodies of the other overflow samplers (paragraph 3.2.2.1).
24. During next field trials one should sample the overflow by using the Bottle sampler at different depths in the overflow in order to investigate the effect of sampling depth on the quality of the samples:
 - a. At the end of the overflow pipe, just above the vessel's hull.
 - b. In the pipe, one or two meters below the funnel.

12.3.5 Overflow sampling results analysis

25. The dataset of overflow measurements results appears to be very valuable. In this work, analyses are performed in order to improve our understanding on what the data is telling us. It is recommended to go further into these results, thereby focussing on the impact of taking fewer samples on the existing outcomes.
26. From the statistical analyses (chapter 10) it appears that the measuring results of the Flow through samplers were quite the same. In future research one should therefore try to use the results of the Flow through samplers in the set up of this analysis, instead of the results of the Front-Flow-through sampler only.
27. During this analysis the overflow discharge was considered to be constant. However in reality it is not. The reason for keeping these values constant was the fact that the order of magnitude of these variations was too small to pick these up from the balance output graphs (appendix 9.1 and 9.2). In future research one should try to bring these variations into account in the set up of analyses.
28. It is recommended to perform this specific research also on the remaining 10 trips. Moreover, it can be useful to compare these results with the results of specific hopper sedimentation models.

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