Seek, and ye shall find
Guidance for borrow area management

Final thesis report

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Cover design: P.R.M. den Broeder
Circulation: 2007
Company: Van Oord dredging and marine subcontractors bv (VODMC)

Seek, and ye shall find – Guidance for borrow area management

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June 2007 – with summary
Keywords; Borrow area management, dredging, van Oord, Bahrain, North Bahrain New Town

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1. Preface

This is my final thesis report of my study, civil engineering. The topic of my final thesis is borrow area management. This topic was submitted by van Oord Dredging and Marine Contractors. The graduation period was spent in Bahrain, on the North Bahrain New Town project at the Planning and Engineering department.
I hereby want to thank van Oord Dredging and Marine Contractors for giving me the opportunity to do my final thesis for them. I want to thank them for its cooperation and all the time and money that were spent on this final thesis. I specially want to thank René Ratsma who did everything what was possible to find a suitable topic for me.
Also I want to thank my mentors for guiding me through this period. From van Oord I want to thank P. Heijgen, M. den Broeder and M. van den Heuvel. From the Hogeschool Utrecht I want to thank F. van Heerden and T. Rinkema for all the time they invested on my graduating period.

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Summary

English:
Before reading the actual final thesis report, first a summary is given. This final thesis report is about borrow area management. Borrow area management is a strategic analysis and monitoring of the supply of sand in the marine borrow areas, so anticipation on changes in the available volume estimate, can take place on time. This is especially important for project with a limited supply of sand. Borrow area management is also important in order to win the available supply of sand in an economical manner.
At the beginning of the graduating period a plan of approach is written. This plan of approach is used as a guide during the graduation period. In the plan of approach is given that there will be written a site specific borrow area management plan. This is left out of concern in this report. The information that is gathered and the working method that is developed on the North Bahrain New Town-project is used to write a general plan how to manage a marine borrow area. This results in a borrow area management plan that can be used for all coming dredging project in the world. The title of this report is “Seek and ye shall find”. The title suggests that borrow area management is an easy issue, but in reality it is very hard to manage a marine borrow area. Constant changes of available sand, equipment and requirements of the sand fill makes borrow area management a big puzzle in which you can get lost. Like the picture on the front page implies.

Nederlands:
Voor het lezen van het uiteindelijke rapport wordt hier eerst een samenvatting gegeven. Dit afstudeerrapport gaat over zandput management. Zandput management is het strategische analyseren en bijhouden van het aanwezige zand in de wingebieden, zodat er op tijd kan worden geanticipeerd op veranderingen in de geschatte volumes. Dit is vooral belangrijk voor projecten waar de hoeveelheid aanwezig zand beperkt is. Zandput management is tevens belangrijk voor het winnen van het aanwezige zand op een zo economisch mogelijke manier.
In het begin van de afstudeerperiode is een plan van aanpak geschreven. Dit plan van aanpak is gebruikt als houvast gedurende de afstudeerperiode. In het plan van aanpak staat dat er een project gerelateerd zandput managementplan zal worden geschreven. Dit is echter buiten beschouwing gelaten. De informatie die is verzameld en de werkmethode die is ontwikkeld op het North Bahrain New Town project is gebruikt voor het schrijven van een algemeen zandput managementplan. Het resultaat is een zandput managementplan dat kan worden gebruikt voor alle baggerprojecten in de toekomst. De titel van dit rapport is: “Zoekt en gij zult vinden”. De titel suggereert dat het managen van een zandput een makkelijke opgave is, maar in werkelijkheid is het lastig. Constante veranderingen van de aanwezige zand volumes, materieel en vraag naar verschillende kwaliteit zand op het stort maakt het managen van een wingebied een grote puzzel waarin je kunt verdwalen. Zoals de figuur op de voorpagina illustreert.

Introduction

The graduating period is spent on the North Bahrain New Town project. This project is a dredging project where a large area will be reclaimed. The north Bahrain new town project has been calculated mainly as a cutter suction dredger project. Because of disappointing quality of the sand, less volume than expected is available for the reclamation from the proposed marine borrow areas. Now the project is executed with mainly trailer suction hopper dredgers. These trailer suction hopper dredgers can remove the sand further from the reclamation and reduce the amount of fines by the means of overflow. This improves the quality of the dredged material.

In order to implement the sand occurrences fully, a borrow area management plan is written. Borrow area management is a strategic analysis and monitoring of the supply of sand in the borrow areas, so anticipation on changes in the available volume estimate, can take place on time. The final result will be a supporting document that can be used for all the future projects in the gulf region.

Abbreviations

BAM	Borrow Area Management
BP	Before Present
BS	British Standard
BWME	Boskalis Westminster Middle East
CP	Coupling point
CPT	Cone Penetration Test
CSD	Cutter Suction Dredger
EDC	Environmental and Dredging Consultancy
HU	Hogeschool Utrecht
IADC	International Association of Dredging Companies
ILS	International Laboratory Services
MBA	Marine Borrow Area
NBNT	North Bahrain New Town
TNO	Toegepast Natuurwetenschappelijk Onderzoek
TSHD	Trailer Suction Hopper Dredger
VDMS	Vessel Data Monitoring System
VODMC	Van Oord Dredging and Marine Contractors bv
VOUB	Voortgezette Opleiding Uitvoering Baggerwerken

List of symbols

A	surface	[m^2]
B	breadth of the hopper	[m]
d	particular size of the fraction	[m]
D	diameter of the pipe	[m]
g	gravitational force	[m/sec^2]
G	weight	[tons]
L	length of the hopper	[m]
M	weight	[kg]
n	number	[-]
η	kinematical viscosity	[m^2/sec]
ρ	density	[kg/m^3]
Q	discharge	[m^3/sec]
σ_n	standard variation	[-]
T	time	[min]
μ	average	[-]
V	volume	[m^3]
v	velocity	[m/sec]
γ	density	[tons/kg]

2. North Bahrain New Town

In this chapter some general information of the north Bahrain new town (NBNT) project will be forwarded. The information will give details of the circumstances and location of the NBNT project.

2.1 Location

The NBNT project involves the development of new islands off the coast of the town Al Budaiya in Bahrain. NBNT is situated along the north-western coast of Bahrain. Bahrain is an island in the Arabian Gulf, which is located in the Middle-East. On figure 2.1a Bahrain is on the left side and on the right a satellite picture of the NBNT project is given (January 2007).

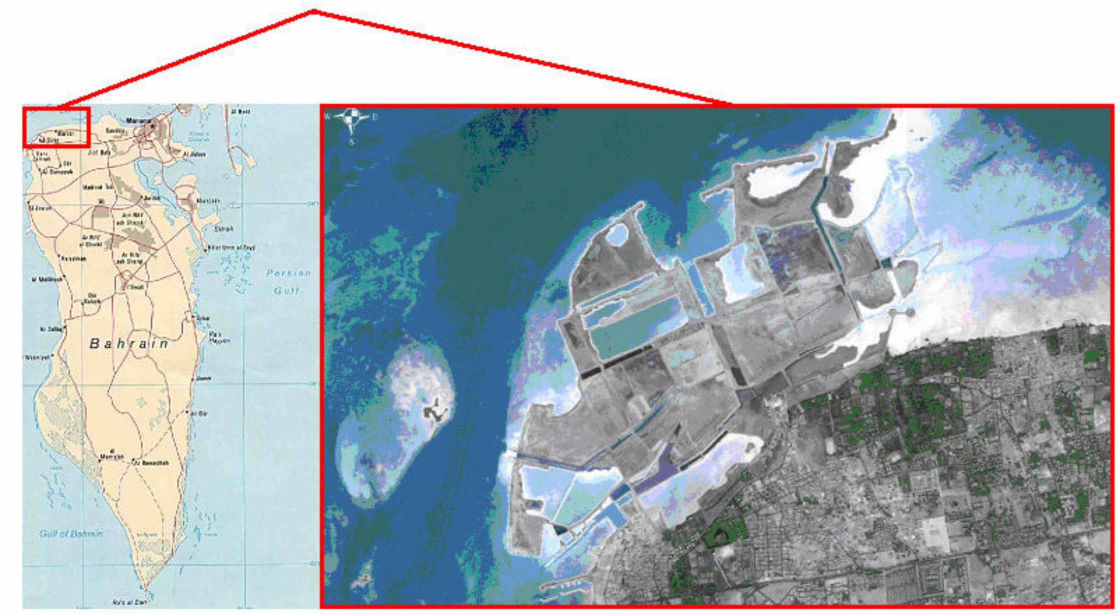


Figure 2.1a: The project location

2.2 Project

The project consists of several separated islands with a total surface of 690 ha. For the project about 34,9 million cubic meters of sand is required.
The islands are physically separated from each other and the existing coastline. In a later stage all separated islands and the mainland will be connected by bridges.
The islands will be developed for residential, commercial and industrial use. On figure 2.2a the NBNT project is displayed. The project exists of several islands, which are numbered.

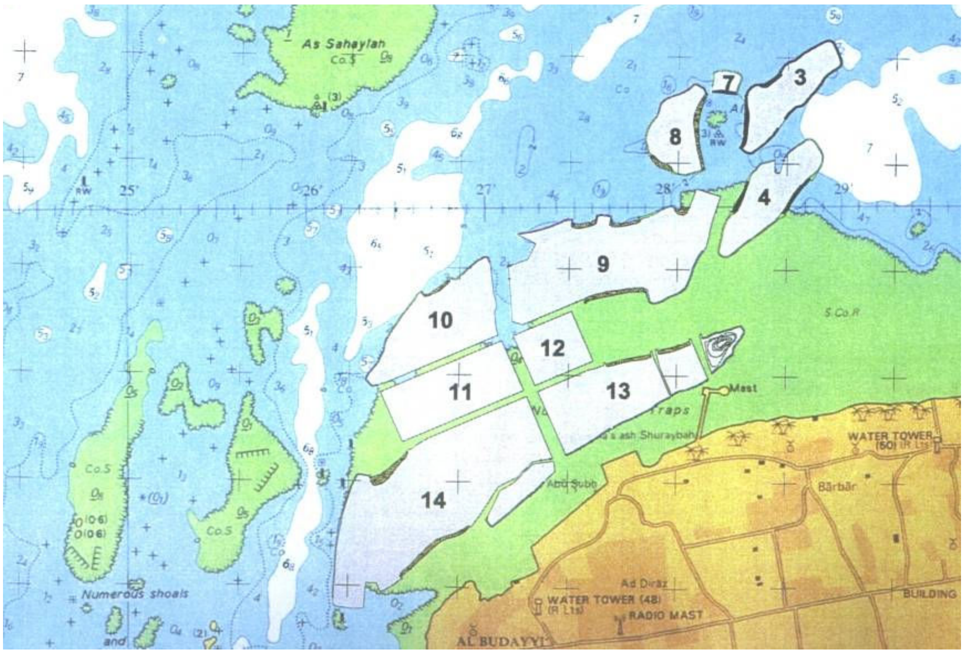


Figure 2.2a: The NBNT project

The work comprises the following activities;

- Reclamation of ten islands.
- Dredging/excavation of external and inner channels.
- Rock armoured slope protection.

Suitable fill material will be dredged from marine borrow areas (MBA's). The reclamation areas are surrounded by a bund construction, so the reclamation works will be performed in enclosed basins. In an enclosed basin the losses are less than in an open reclamation and no turbidity of the surrounded water take place. This fact is important, because the project is surrounded by protected fishing grounds, where prawns bread. Also sea grass grows in the vicinity of the project, this is eaten by turtles.
Unsuitable fill material will be placed in the so called green areas; these are places where no heavy constructions will be developed. In these areas (parks e.g.) there is no special requirement as to bearing capacity.

2.3 Marine borrow areas

The MBA's of the NBNT-project are displayed in figure 2.3a. The cutter suction dredge areas are located close to the reclamation area. The trailer suction hopper dredge areas are located further away from the reclamation. Because some areas of the MBA's are very shallow; channels had to be dredged in order to make all the MBA's available. The channels are dredged by CSD's in the beginning of the project. In figure 2.3a the channels are displayed in red. The first channel is very close to the reclamation and is made in order to get to the coupling point (CP). The second channel is a small passage between MBA 3 and MBA 4. The third channel is a 2 kilometers long channel between MBA 4 and MBA 5.

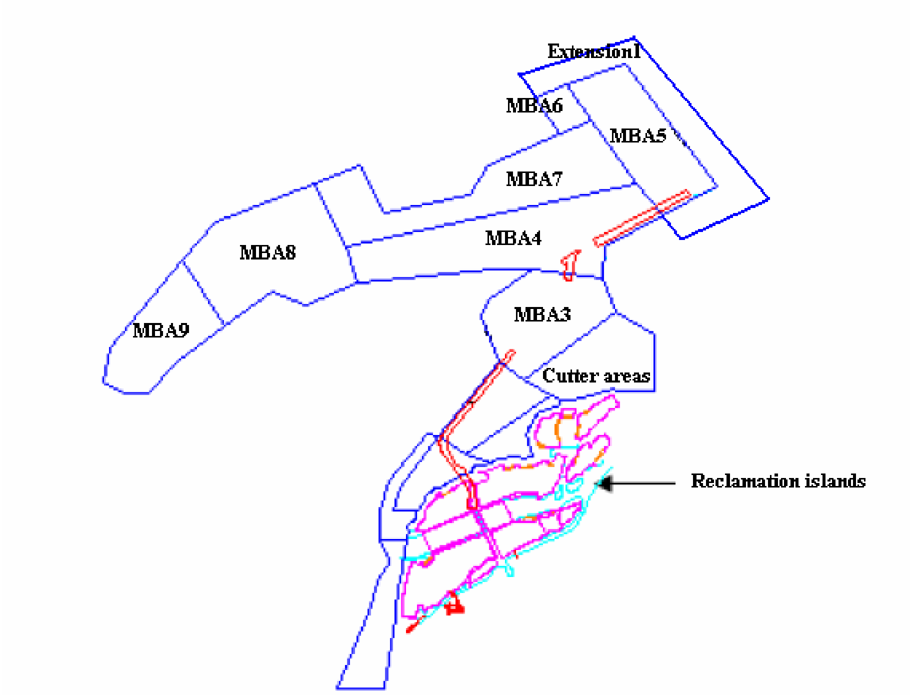


Figure 2.3a: The marine borrow areas of the NBNT-project

The east side of MBA 4 and 7 and the north side of MBA 7 exist out of shallow areas. In order to sail to or from MBA 5,6 and extension 1 the TSHD have to sail through the 2 kilometer long navigation channel. Because there are more TSHD's on site the cycle times of the TSHD's have to be adjusted to each other.

2.4 Site organization

The site organization for the NBNT project consists of a joint venture between Boskalis Westminster Middle East (BWME) and Van Oord Dredging and Marine Contractors (VODMC). NBNT is a joint venture to control and spread the financial risks that extensive projects bring. On figure 2.4a the set up of the site organization is displayed.

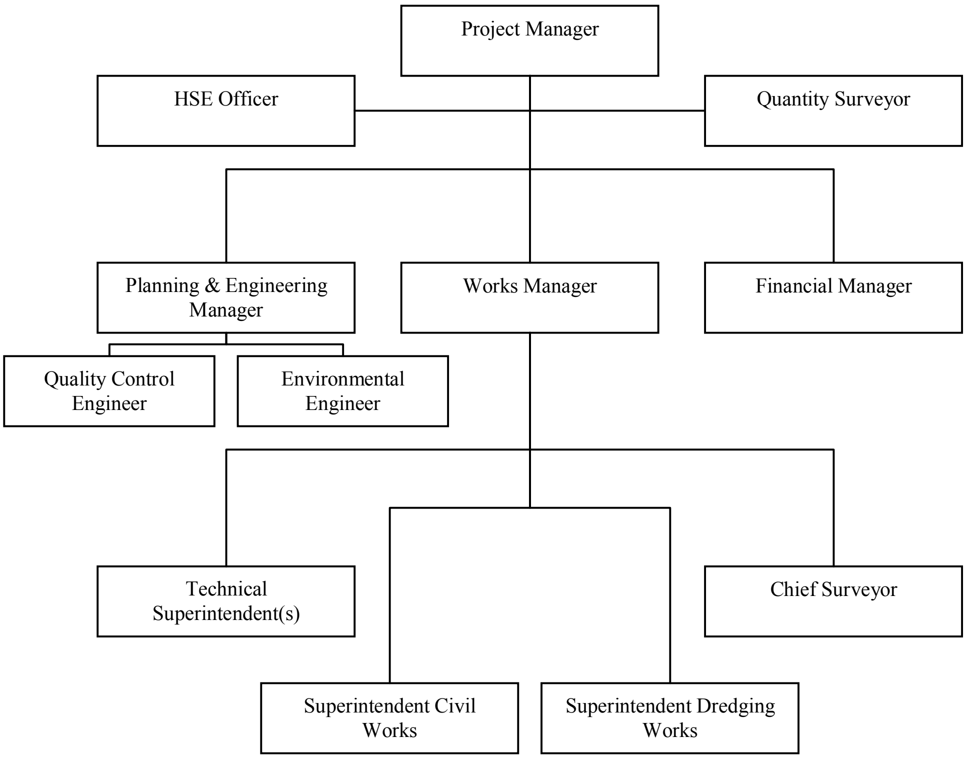


Figure 2.4a: The set up of the site organization

Everybody in the organization has its own activities, but BAM is something that involves the entire site organization. Information that is used for BAM comes from all corners of the site organization.

2.5 Equipment on site

In this paragraph the most important equipment for BAM is mentioned. The equipment that doesn't influence the BAM is left out of concern.

2.5.1 Trailer suction hopper dredgers

TSHD's are self propelled vessels, with its own loading and discharging installation. Basically the TSHD works like a large vacuum cleaner moving over the seabed. The dredged material is deposited inside the hopper of the TSHD. Here the material can settle and the water and fine material run overboard through the overflow. When the TSHD is loaded it sails towards the coupling point. Here the TSHD pumps the material through a pipeline towards the sand fill.

The TSHD's and their specifications that are used on the NBNT project can be found back in Appendix 1.

Work limitation
The TSHD's are not applicable on every project. The TSHD's have got the following limitations:

1. TSHD's need sufficient water depth to sail; this depth is depending on the following data:
- Draught of the TSHD.
- Keel clearance for squat, survey inaccuracies and safety (1 meter)
- The water depth may also not be too large, because of the limited length of the suction pipe.

2. The maneuverability of a ship depends on the following data:
- The dimensions of the ship
- The dimensions of the area where the TSHD sails. The minimum width for turning is one and a half time the length of the vessel. The water width should be at least 4 times the length of the vessel to make sure the TSHD can continue dredging without lifting the drag head (also the current influences this).

3. The weather conditions give also limitations to the TSHD
- The wave heights should not be higher than 2 to 4 meters.
- Strong current, especially not on the flank of the TSHD.

Production limitations
The production of a TSHD depends on a certain number of factors, which can be separated in internal and external factors:

External factors:
- The dimensions of the MBA
- Water depth
- Tidal range
- Current velocity
- Soil conditions (sand layer thickness, fines, H_2S, D_{50} etc.)
- Restrictions laid-up by the authorities (like sailing speed, overflow and dredging depth restrictions).
- Sailing distance
- Discharging distance
- Waiting time on other ships due to limited dimensions of the channels.
- Waiting time on other TSHD's, because of limited number of coupling points (CP's).

Internal factors:
- Type of drag head
- Pump capacity (suction and discharge pump)
- Trailing speed
- Distance of pump under water
- Design of the hopper

Reason to choose for a TSHD:
- No or not enough suitable material can be found close to the reclamation area.
- No anchor wires are required, so they form no obstruction to other vessels.

2.5.2 Cutter suction dredgers

A CSD is a stationary dredger which cuts the soil and transports the material hydraulically. The material is loosened by the cutter head and pumped through a pipeline directly to the reclamation area or side casted. The material is side casted when the distance to the reclamation area is too much. The CSD can side cast the material which can be picked up by the TSHD's. The CSD pushes itself forward by the means of a spud carriage system. It also swings around this spud point during the excavation work.

The CSD and its specifications as used on the NBNT project can be found back in Appendix 1.

Work limitation

The CSD's are not applicable everywhere. The CSD's have got the following limitations:

1. It is not recommendable to use CSD's in areas where is a lot of traffic, because the side wires will block the passage.
2. It is not possible to use the CSD far away from the reclamation area (with the exception of filling a barge or side casting).
3. A CSD can work only if the wave height is not larger than 0,5 to 1,0 meter.
4. CSD's cannot work when the current velocity is higher than 1 to 1,2 m/sec.
5. The CSD's have a maximum dredging depth, for the biggest CSD's the maximum dredging depth is around 30 meters.
6. In general the minimum dredging depth is around 1 meter; this depends on the design of the CSD.
7. Restrictions imposed by authorities (like sound, dredging depth and environmental restrictions).

Production limitations

The production of a CSD depends on a certain amount of factors, which can be separated in internal and external factors:

External factors:

- Soil conditions
- Current velocity
- Wave height
- Traffic
- Distance between MBA and sand fill
- Dredging depth
- Restrictions imposed by authorities

Internal factors:

- Type of cutter head
- Type of teeth
- Pump capacity
- Cutter power (when dredging rock)
- Discharge distance

Reason to choose for a CSD:

- Material like rock and stiff/hard clay has to be dredged.
- Channels have to be made in shallow areas.
- Channels for the TSHD's have to be made.

In general CSD's are cheaper than TSHD's, so material close to the reclamation area should be dredged with a CSD.

2.6 Required quality in reclamation

In the reclamation suitable fill material is required, in order to meet to the requirements that are mentioned in the contract.

Suitable fill material contains organic matter or materials that have a content of fines (particles passing the BS 0,063 mm test sieve) less than 10%. Pieces of rock or boulders with a maximum dimension of 300 mm shall not be tolerated as suitable material for the reclamation.

For the artificial beaches other requirements exist. The colour of the fill material must be close to the beaches in surrounding areas. The grain size of the material must correspond to coarse sand, with a D_{50} comprised between 0,4 and 2 mm. The amount of fines over the total beach may not be larger than 5%.

If the quality of the dredged or excavated material is unsuitable it should be placed and mixed in the green areas, where hills, parks and schools are being developed.

2.7 Required quality in MBA

The TSHD can reduce the amount of fines from the fill material by the means of overflow. This way the material that in the first place seems to be unsuitable for the reclamation, becomes suitable. Coarse sand will settle in the hopper of the TSHD, while the finer material disappears out of the TSHD by the means of overflow. This is the reason that sand containing more than 10 percent of fines in the MBA can become suitable as fill material. For the NBNT-project this is investigated and the result can be found in paragraph 7.5).

In Table 2.7a you can see when the material that is in the MBA is suitable or not. An “U” means that the material is unsuitable an “S” means that the material is suitable. This depends on the D_{50} and the amount of fines that is found in the material from the MBA.

d50 [mu] \ fines <63 um [%]	0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45	45–50
350–400	S	S	S	S	S	S	S	S	U	U
300–350	S	S	S	S	S	S	S	U	U	U
250–300	S	S	S	S	S	S	S	U	U	U
200–250	S	S	S	S	S	S	S	U	U	U
150–200	S	S	S	S	U	U	U	U	U	U
100–150	U	U	U	U	U	U	U	U	U	U
50–100	U	U	U	U	U	U	U	U	U	U
0–50	U	U	U	U	U	U	U	U	U	U

Table 2.7a: Classification schedule, which is based on experiences in the past *

The schedule above is based on experiences of HAM dredging in the past. According to the schedule a sample with a D_{50} of 175 µ and a percentage of fines of 22 is unsuitable material. A sample with a D_{50} of 200 and a percentage of fines of 17 is suitable as fill material.

* Source: H448 Penny’s Bay

3. Available sand volume

The first thing that has to be done before starting with BAM is to know the location, the quality and the amount of sand that is available in the MBA's. From the Soil Investigation (SI) comes a gross volume of sand that is available for the reclamation area. The gross volume will be reduced by reduction factors and the net available sand is known. In this chapter all steps to come to the net sand volume will be elaborated.

3.1 Soil investigation

The soil investigation is very important for BAM. That's the reason that the following paragraphs are dedicated to this subject. There are many different ways to execute SI. In this chapter the most important methods of SI for BAM are elaborated. From the SI the gross available sand is calculated.

3.1.1 Importance of soil investigation

The awarding authority comes with a design, with conditions. The contractor combines the tender with their equipment and know-how and comes up with a tender price. The contractor with the lowest price and the best conditions will eventually get the job.
The design can exist of an area that has to be reclaimed and/or an area that has to be excavated.
The SI is used for the cost calculation in the tender phase. An inaccurate calculation can lead to a project that doesn't make any profit. Errors in cost calculation are mostly the result of unexpected changes in work method or changes in used equipment, like in case of the NBNT-project. It also can happen that the project is awarded to another contractor, because the calculated price was too high. To make a cost calculation several steps have to be taken. In figure 3.1a all steps are displayed that have to be taken to come from a design to the tender price.

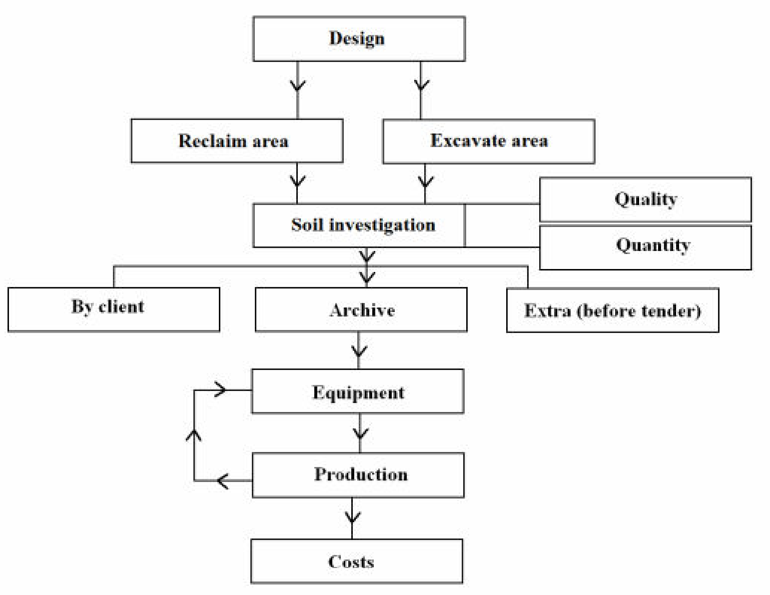
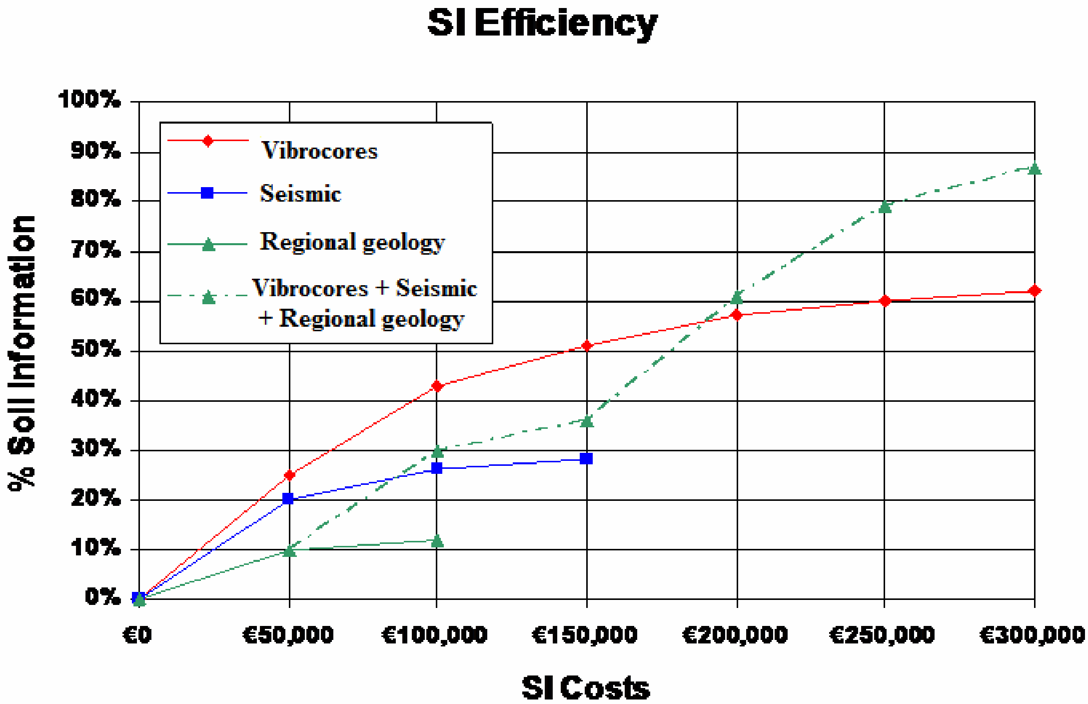


Figure 3.1a: How to come from a design to the tender price

The soil of the excavation area, reclaimable areas and the marine borrow areas will be investigated. In this soil investigation (SI) the quality, quantity and location of the sand is thoroughly investigated. The awarding authority, mostly gives a soil investigation together with the design. Sometimes the contractor has done a project near by and he can use this soil data for the new project, to get a better picture. If the soil investigation is not sufficient the contractor can decide to do extra SI. The more SI is done, the lower the risk for the contractor. The risks should be weighted to the costs of a SI.



Graph 3.1b: The SI efficiency[†]

In Graph 3.1b the cost of a SI is set out to the information that the SI gives. The more is invested in SI the more soil information is known. This information can reduce the risks and avoids problems during the execution of the project. The graph only gives an indication about the cost of a SI and is depending on the dimensions of the project and the soil conditions. Big projects with a heterogenic soil require more SI than smaller project with a homogeneous soil. A combination between methods gives more soil information for the same amount of money.
When the previous is all done the equipment can be chosen. This is done by looking at the working and production limitations of the equipment (see paragraph 2.5).
When the equipment is chosen, the production calculation can be made. If the production during the project is too low to secure that the end date of the project will be reached on time, other or more equipment has to be selected.
The final step is to make a cost calculation; this calculation is used to come to a final tender price. Risk is also included in the tender price and has its own price. The contractor also can define conditions to lower the risk, and with this lower the tender price.

[†] Source: Marcel van den Heuvel, van Oord

The cost calculation of the NBNT-project depends in big lines of the following:

1. Demobilization costs
2. Equipment (CSD's, TSHD's, tugboats, etc)
3. Equipment (floating pipelines, valves, pipelines, generators, etc)
4. Fuel and lubrication
5. Maintenance costs
6. Mobilization costs
7. Profit
8. Repair costs
9. Risk
10. Salaries
11. Site office
12. Subcontractor stone work
13. Subcontractor machine rental
14. Subcontractor personnel
15. Subcontractors (tugboats, speedboats)
16. Soil investigation
17. Interest and depreciation

The biggest share of the costs is calculated to the CSD's and TSHD's that are on site.

3.2 Elaboration of soil investigation methods

In the following paragraphs the methods of soil investigation for BAM are elaborated. The methods are elaborated in the following order: Multi beam, regional geology, seismic, vibrocores, lab results and eventually the result of the soil investigation. The final result will give the net sand that is theoretically available for the reclamation.

3.2.2 Multi beam

Before ships of van Oord are allowed to dredge in the MBA' a multi beam survey has to take place in this area, this is done for safety reasons. A multi beam is a type of echo sounder that transmits sonar beams in a cone shape in stead of one beam straight underneath the ship. With this method the entire seabed is scanned, in stead of a line underneath the ship. The sounds have a high frequency and a low wave length, therefore they bounce of when they hit the seabed. All signals that are sent out reach the seabed and return at slightly different times. These signals are received and converted to water depths by computers and then plotted as bathymetric maps.

This distance has to be corrected with the tidal level at that moment. With this method the seabed is mapped out accurately. The data is transferred to the computer on the TSDH's and the TSHD's can sail safely, without getting grounded in shallow areas.

3.2.3 Regional geology

Before starting the SI it is important to look at the regional geology. This way you already have a picture of what you might find during the SI.

For the NBNT-project the following applies[‡]:

In the Arabian Gulf the sea level was 21.000 to 20.000 years ago about 120 to 130 meters below the current level. The sea had retreated fully from the Arabian Gulf, the climate was arid and the dominant type of deposition was wind blown (Aeolian). The sea occasionally transgressed into the deepest parts of the Gulf where the precursors of the Euphrate and the Tigris flowed.

From 18.000 to 12.000 BP the climate was more humid and in the deeper parts of the gulf thick layers of sediment where deposited. In this period the sea level was 30 meters below the current level.

From 12.000 to 9.000 BP the climate was arid and wind blown sediments and carbonates were deposited. Deposits close to Bahrain consist of coral sand and gravel, limestone grains, coral and shell banks and hard bottoms.

[‡] Source: Gas venting and late Quaternary sedimentation in the Persian (Arabian) Gulf

After 9000 BP the regional climate became humid again, and after 3000 BP the climate gained its current status of extreme aridness. In this period till now, so called *shamals* blow fine sand into the sea. In this period also fluvial sediment and carbonates, are transported by rivers in Iran,

From the above can be concluded that the bottom must exist out of different layers of sediment. The sediments that are likely to be found are: Sand, carbonate, shells, coral, gravel, limestone and fluvial material like clay.
Because of the rise of the sea level it is wise to check the inland; here similar sedimentation took place. So the material in mountains and hills give you a good picture of the material that you might find in the seabed of the MBA's.

3.2.4 Seismic

Seismic investigation is done by pulling a sounding "fish" through the water that sends out acoustic signals. The sounds have a low frequency and high wave length; therefore they penetrate into the seabed or bounce of when hitting a layer with difference in compaction. The ship sails lines on a certain grid. A part of the acoustic waves reflect where a difference in compaction is; other signals penetrate deeper into the seafloor, and bounds off between two layers of sediment. The signals that bounce off will go to the surface a will be picked up by the sensors. The result of this analysis indicates the structure of the layers of sediment beneath the seafloor.

On figure 3.2a is the result of a seismic survey displayed; the different layers are clearly visible.
Boreholes or vibrocores are necessary to know what kind of material is present in these layers. The combination of the vibrocores together with the seismic gives a good picture of the different layers of the seabed.

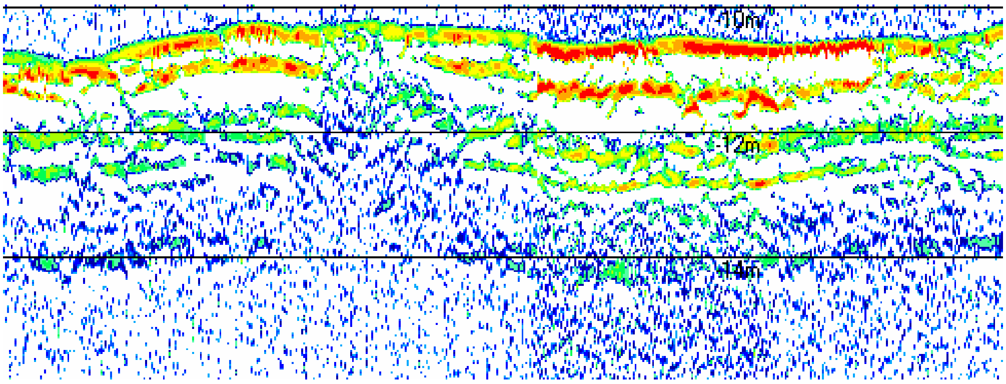


Figure 3.2a: Seismic picture of the seabed in Bahrain (gross sediment)

3.2.5 Vibrocores

Vibrocoring is a coring method for underwater sampling.
On a drilling platform a sample core is vibrated into the seabed, by a vibrator. The depth of the drilling depends on the soil material. In sand the vibrocore can penetrate about 8 meters into the seabed. The drilling is stopped when the vibrocore is fully filled or gets too much resistance. The sample that stays in the core catcher can now be brought up. The coordinates were the vibrocore took place is written down, so the location of the vibrocore is known. The samples can be described and brought to the laboratory for sieve analyses, so the amount of fines and D_{50} is known.

It is possible with vibrocoring to take many samples in a relative short period. TSHD's can only remove the loose top layer of the seabed and have a similar penetrating capacity as a vibrocore. That's why this method is sufficient in TSHD's dredging areas.

In Appendix 2, a vibrocore is displayed that is made on the NBNT project. The vibrocore shows two different layers of sand with underneath a layer of siltstone.

3.2.6 Lab tests

The promising samples (likely to be sand) from the vibrocores are analyzed in the laboratory. The sample is mixed together and a small sample is taken from it. A smaller sample is made because the sample has to be dried in the oven. When you put a big sample in the oven it would take too long until the sample is dried and it would take too much oven capacity. After drying, the samples can be sieved and the sieve curve can be drawn. Out of this curve, the D_{50} can be determined, so the D_{50} and the percentage of fines are known. An example of a sieve result from the NBNT-project is given in Appendix 3.

3.3 Results of soil investigation

The results from the SI can now be brought together and the quantity, location and quality of the sand are known.

The quality of the sand is given lab results together with the coordinates of the vibrocores. The quality can be compared to the required quality as it is mentioned in paragraph 2.7.
The gross volume of sediment is given by the multi beam, regional geology, vibrocore and the seismic.
The gross quantity of sand is given by the multi beam, national geology, seismic, vibrocores and lab results. The result for the NBNT-project can be seen on the next page, in figure 3.3a.

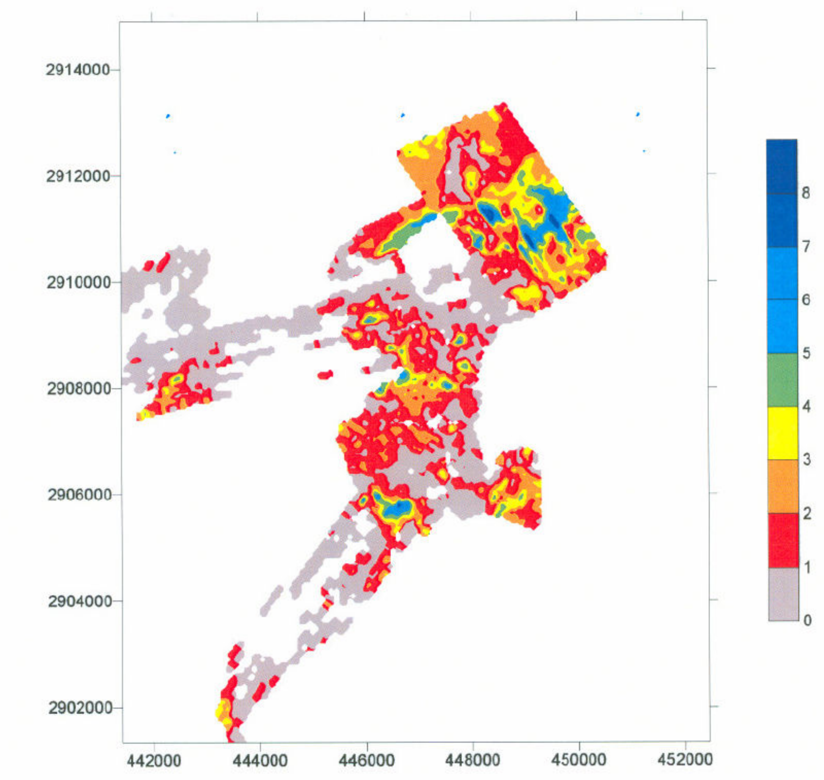


Figure 3.3a: Overview of the sand thickness in the MBA's (gross sand)

On figure 3.3a the thickness of the gross sand layers in the MBA's are displayed. The thickness of the layers is varying from 0 until 8 meters.

During the execution of the project the dredged material should be compared with the SI. Differences between the two should be analyzed. It is possible that some layers are interpreted incorrect, then the SI should be corrected.

3.4 Available sand for reclamation

Not all sand can be extracted from the MBA on a economical manner and this way it is not available as fill material for the reclamation, this is because 5 reason's which will be elaborated in this paragraph. Figure 3.4c gives the schedule to clarify the volume calculation. The schedule gives information, how to come to net volume of sand that can be won in an economical manner. The schedule is displayed on page 26.

- In shallow areas the volumes can not be extracted, because of the draught and the keel clearance of the TSHD's.
- A restriction of the maximum dredging depth. On NBNT-project it was not allowed to dredge deeper than 5,5 meters, because of sweet ground water that is floating underneath the seabed.

- All layers with a thickness of less than 0,5 meter are defined as not dredgable.

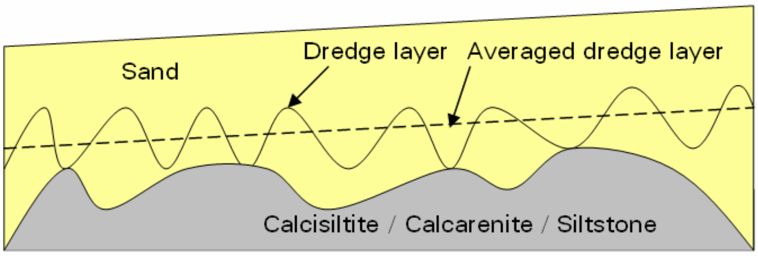


Figure 3.4a: The movement of the drag head on the seabed

The drag head bounces of on a hard layer that is present in some areas in the MBA; these irregularities in the seabed hinder the dredging process increasingly (as illustrated by figure 3.4a).

- A maximum of 2 meters of sand can be extracted from the seabed; because undredgable materials like big rocks will stay behind. Because of this the MBA will get polluted with rocks that stay behind, so the dredging process will become less efficient (as displayed in figure 3.4b). The sand can technically be removed but not in an economical manner.

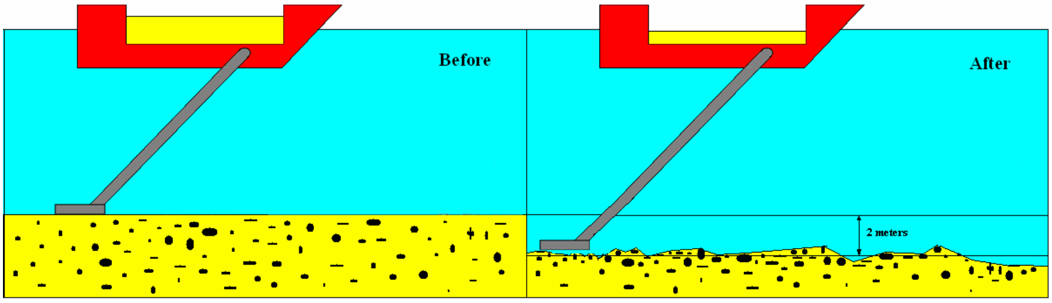


Figure 3.4b: How a MBA gets polluted with rocks

- The remaining volumes has been put on an efficiency of 50 percent, this is done on experiences in the gulf region in the past. After a while the efficiency of the MBA becomes less. The efficiency becomes less because in some areas all the sand is dredged and in other areas there is still some material left. Overall the efficiency in the MBA will become less during the time. Also a large volume will disappear out of the MBA. This material is sucked-up and disappears by the means of overflow. The material comes back in the water column and the current takes the material out of the MBA. These are the reasons for the 50 percent recoverability.

The result of the volume calculation is the net volume of sand that can be won in an economical manner. The efficiency of the MBA's on the NBNT-project is calculated in paragraph 7.3.

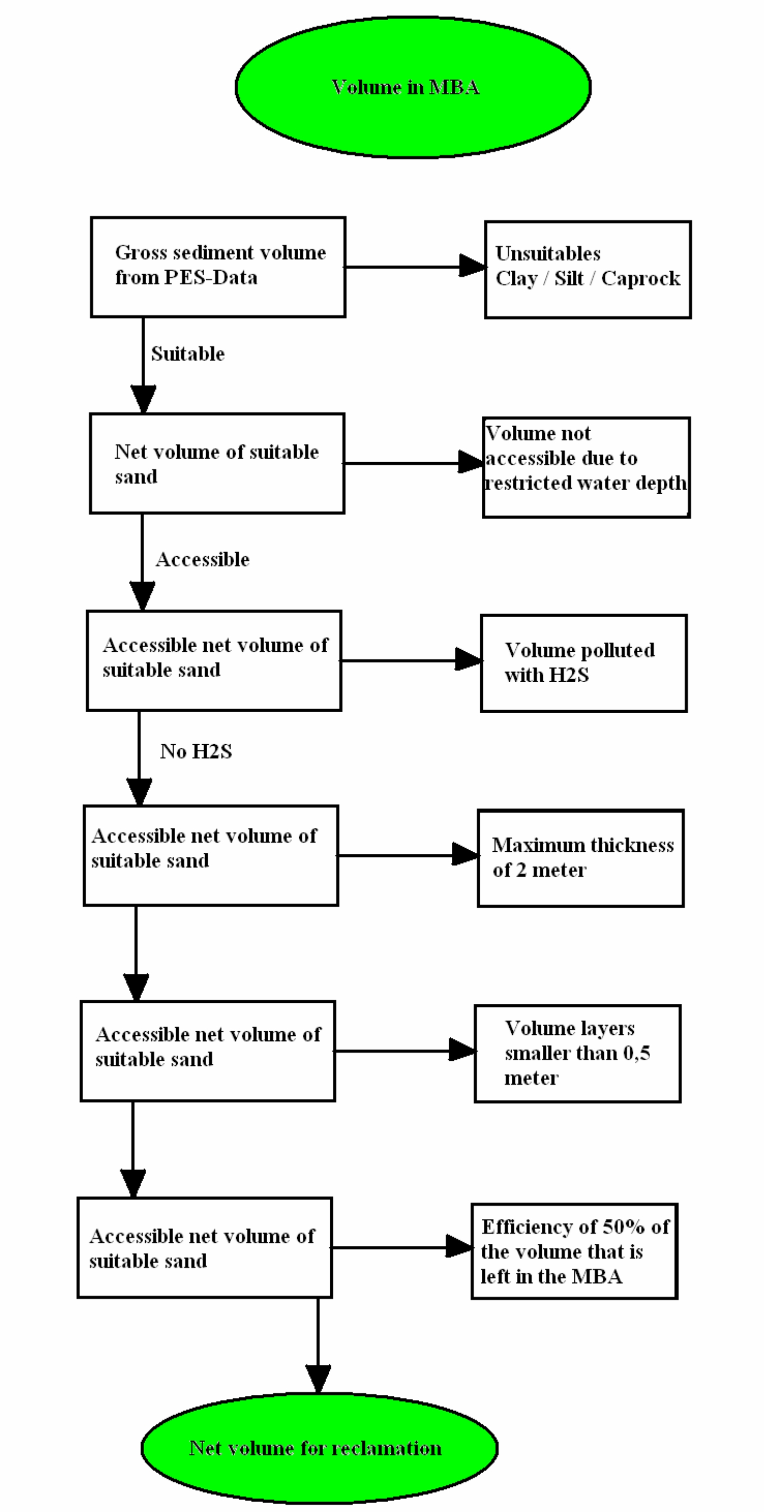


Figure 3.4c: Which volume is available for the reclamation

3.5 Required sand in reclamation

The volume between the in-survey and the design is increased with a factor because there will be losses. At the start of the NBNT-project there was assumed that there are 1/0,86 = 16 % losses. The value of the factor is copied from earlier projects in the Gulf region. The factor is recalculated for the NBNT-project in chapter 7.1. In Figure 3.5a there is a schedule that gives information, how to come from the volume that the TSHD's are bringing to the Net volume that is in the reclamation.
The volume that TSHD's should bring to the reclamation area can be calculated by the following formula:

$$V_{needed} = \left(V_{design} * \frac{1}{0{,}86} \right) - V_{brought,by,other}$$

The losses are caused by the following and can be found back in the schedule that is mentioned above:

- There will be losses in the reclamation area, because fines will pass through the water box and flow back into sea.
- In an open sand fill the losses will be even bigger, because the material will be transported by currents before it can settle.
- Waves will remove material from unprotected slopes of the fill area. This material is taken away by the current.
- The density of the material in the TSHD's and in the sand fill is not equal to each other. The density on the reclamation area is assumed to be higher, because it has more time to settle and heavy machines drive on the reclamation. (This is difference is calculated for the NBNT-project in paragraph 7.2).
- Some material is placed outside the dimensions of the design and is not reachable for excavators.
- Settlement of the old ground level.
- An uncertainty factor is present in the measurement of the volume in the hopper of the TSHD. This is done by lowering down a certain amount of sounding wires on the material over the length of the hopper. This way of measuring only gives a rough picture of the volume that the TSHD is transporting. It can be that this measurement is inaccurate, because the person who executes it reads the measuring tape inaccurate. It can also be that the estimation of the volume by the means of a few measuring points is not sufficient. The time the sounding takes place is also important, because the material will settle inside the hopper. The later the sounding takes place; the lower the volume that is measured.

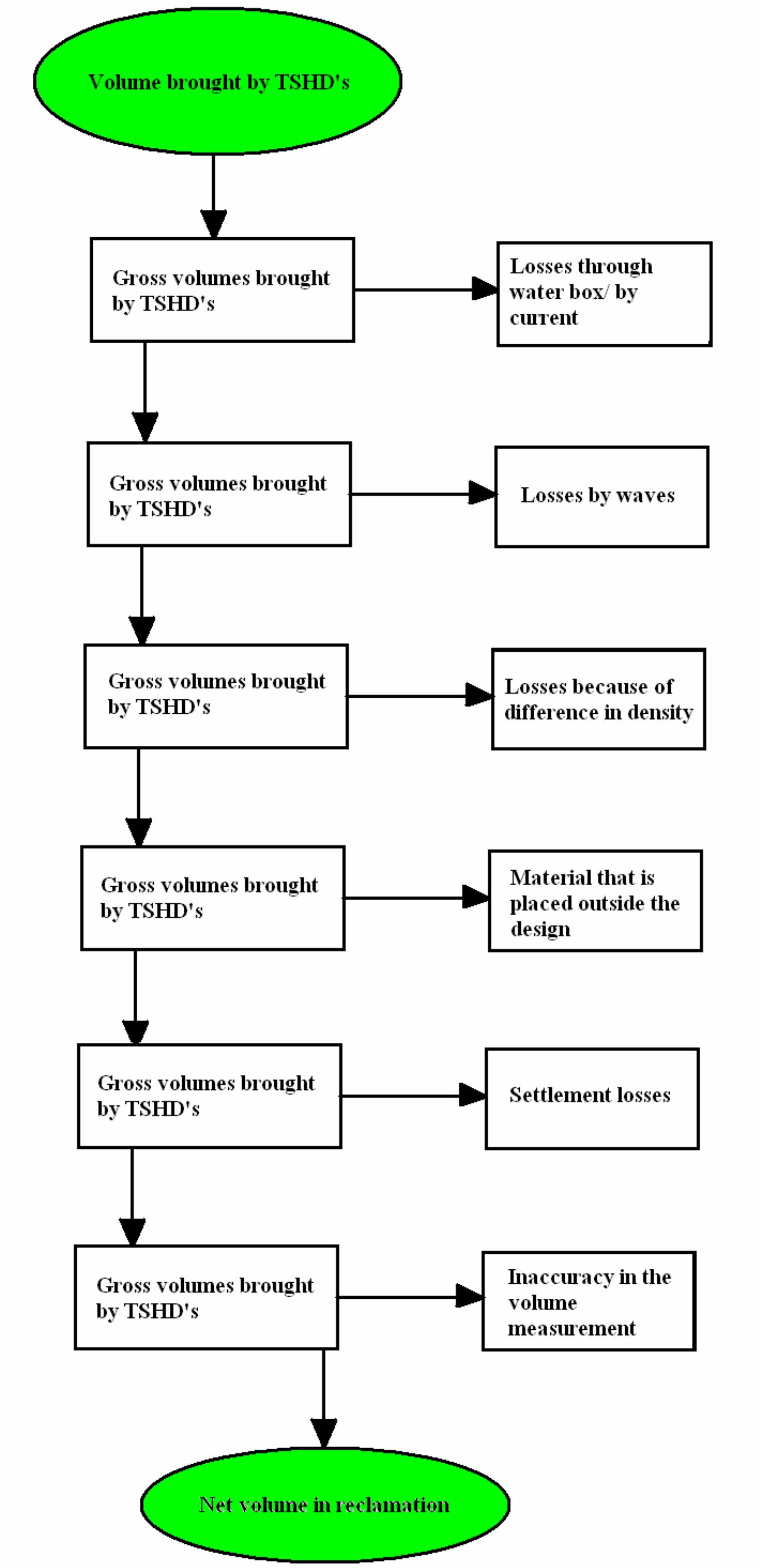


Figure 3.5a: Which volume will be placed in the reclamation

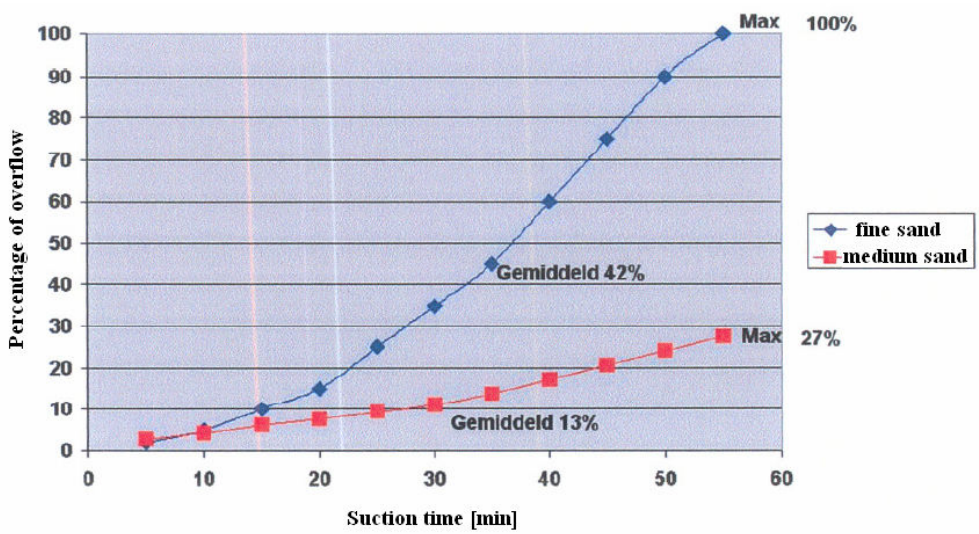
3.6 Handling the available sand

In this paragraph is explained how to handle the available sand volumes. This is important to process the available volume as economically as possible. This way time and money will be saved. The reclamation has its own requirements; this way it is very important to know in which area the TSHD's are dredging and in which area the dredged material is placed.
First the volume in the MBA will be discussed and later how to handle the volume in the reclamation area.

3.6.1 Handling volume in MBA

The quality and quantity of the available sand is dependent on the location in the MBA. In some areas there is a very thick layer present and in some areas there is no material at all. The quality of the material is also dependent on the location. In some areas the sand contains a lot of fines and in other areas it contains hardly any fines.
It is recommendable to dredge in an area were the material is unsuitable and later (on the same trip) in an area were the material is suitable. The suitable and unsuitable material will mix in the hopper of the TSHD and all the material can become suitable for the reclamation area. This operation must be carried out with care. When there is dredged too much unsuitable material the total load can become unsuitable. It is better to dredge unsuitable material in the beginning of the cycle, because the overflow losses will be less. When the unsuitable material is dredged when the hopper is almost full, the velocity in the hopper is very high and all the material will disappear by the means of overflow.
The velocity is high, because the surface of the water is less (see Graph 3.6a).

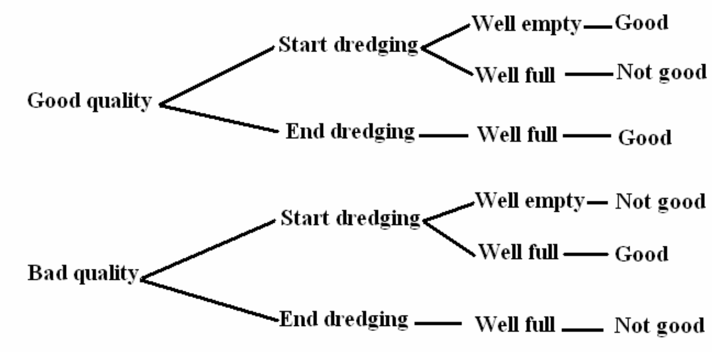
$Q_1 = Q_2 \qquad v_1 * A_1 = v_2 * A_2$



Graph 3.6a: Percentage of overflow losses of North-sea sand[§]

[§] Source: Ecologische effecten en knelpunten bij zandwinning in Nederland, Hong Kong en Singapore

When there are shallow areas present in the MBA it is important to dredge in these areas first. This way the production will not be dependent on the high tide in a later stage of the project. The seabed in these shallow areas will be lowered and the area will also become accessible during the low tides.
It is dependent on the quality of the material how the loading process should take place; this is displayed in Schedule 3.6b.



Schedule 3.6b Quality to loading process

The schedule shows that it is not good to start dredging bad quality material with an empty hopper. The bad quality material will have time to settle in the hopper and the fines stay present in the hopper. When starting dredging with a full hopper, the overflow will start almost immediately and the finer material will disappear by the means of overflow.
When starting dredging in an area where the material is good the hopper should be empty in order to give all the material time to settle, also the fines that are present. This way the losses will be less.
At the end of the loading process the material should be coarse in order to prevent losses (as previous explained).

3.6.2 Handling volume in reclamation

The material that is brought by the CSD is in general of less quality than the material brought by the TSHD. The TSHD should bring on the top layer in order to achieve drainage capacity. A top layer of good material is also good for construction works like road development and it looks visually good. This way it is better that the CSD brings the bottom layer and the TSHD the top layer. The CSD is further left out of concern in this paragraph.
Material with a large amount of fines should be pumped in a large sand fill, in order to prevent high losses. When the distance between the pipe and the water box is large; then the material has more time to settle. A water box makes sure that the water can disappear from the sand fill and gives the material time to settle. A water box works similar to the overflow on board of a TSHD. In a large sand fill the fine material will spread over a large area and will form a thin layer, this is mostly acceptable. The material with a large amount of fines can also be pumped in a small sand fill; this way the quality of the material will improve, but the losses through the water box will be high.

4. Borrow area management

In this chapter borrow area management will be discussed. The BAM-plan is given and explained and the shooting script for BAM is given. In the next chapter the tools for BAM will be treated.
Borrow area management is a strategic analysis and monitoring of the supply of sand in the marine borrow areas, so anticipation on changes in the available volume estimate, can take place on time. BAM is important for projects where the supply of sand is limited.

It is very important to make a BAM plan for the project, this for the following reasons:

- Localize problems in an early stage
- Improve the quality of the reclamation area
- Achieve higher productions during the project
- Minimize costs & time

Borrow area management is dependent on the following factors:

- Amount of sand in the borrow areas
- Amount of sand that is required in the reclamation
- Quality of the sand in the marine borrow areas
- Quality that is required in reclamation
- Location of the sand
- Equipment that is used
- Soil conditions
- Depths of the seabed in the MBA's
- Thickness of the sand layers
- Restrictions imposed by the authorities, like sailing speed, overflow and dredging depth restrictions
- Water level fluctuations, because of tidal differences

4.1 BAM-plan

The BAM-plan is an overview of everything that is involved with BAM. All steps that have to be taken are in the plan. Each step that is taken has its own tools and required information. The BAM-plan is displayed in Figure 4.1a. On the following pages you can find each step of the BAM-plan. At each step the required information is mentioned.

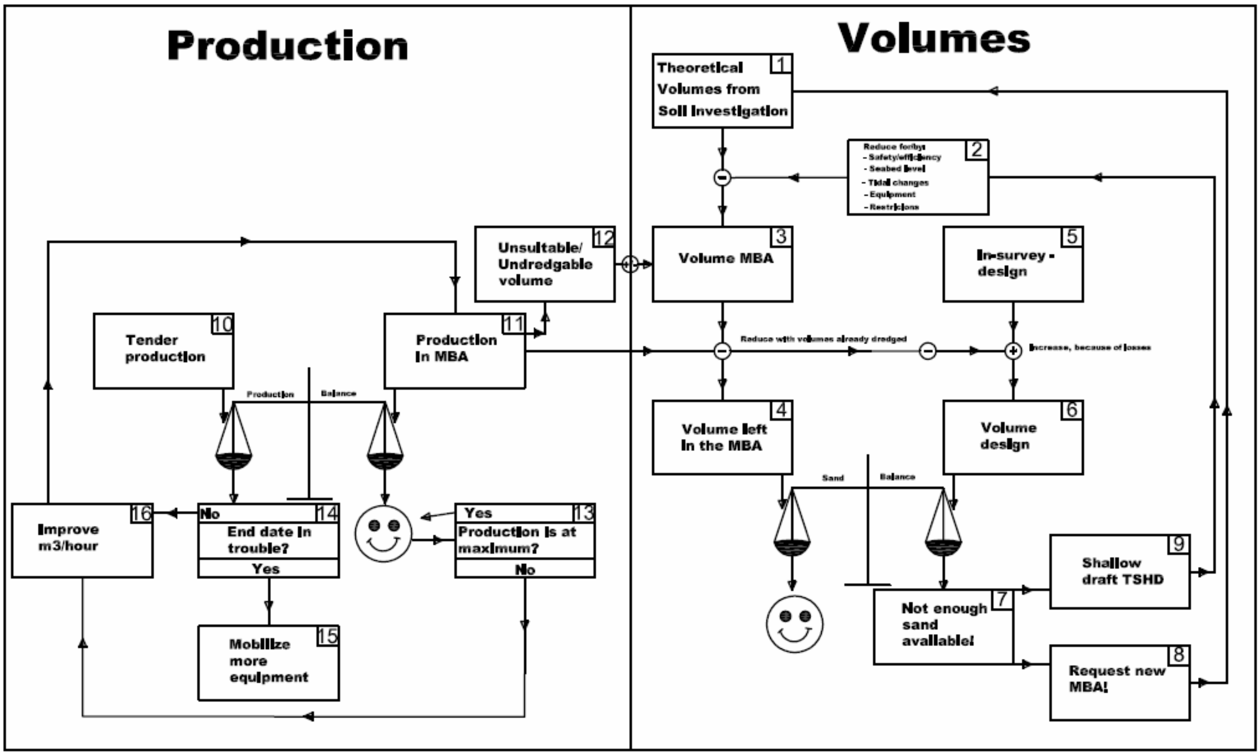


Figure 4.1a: The BAM-plan

1) Theoretical volumes from soil investigation

The theoretical volume is calculated from the soil investigation. In paragraph 3.2 the different kind of SI are elaborated. When a new MBA is released or a shallow draught TSHD came on site the volume should be adjusted. The calculation results in the gross sand volume. The information that is required for the volume calculation is:

- Multi-beam
- Regional geology
- Seismic
- Vibrocores
- Lab results

2) Reduction factors

The volume that is calculated in step 1 should be reduced, because of the reasons that are mentioned in paragraph 3.4. The safety/efficiency factors are:

- Dredge a maximum layer of 2 meters
- Layers thinner than 0,5 meter are undredgable
- The remaining volume is put on an efficiency of 50 percent

The maximum dredging depth of 5,5 meter is site specific for the NBNT-project. The area's that are accessible for the TSHD's is depending on the following factors:

- Specifications of the TSHD (draught)
- Seabed level
- Tide levels

With these restrictions the volume in step 3 can be calculated.

3) Volumes in MBA

The theoretical volume from the soil investigation reduced by the reduction factors gives the net sand volume in the MBA that is available for the reclamation. The volume can be adjusted if there are changes to the SI. Area's that are undredgable according to the SI can be dredgable in reality and visa versa.

4) Volumes left in MBA

The volume in the MBA minus the already dredged volume in the same area gives the volume that is left in the MBA. The exact location of this sand is given by the drag head depth compared with the TNO-layer (see paragraph 5.3 and 6.3). The required information for this is:

- Drag head depths (from the log files)
- TNO-layer

5) Difference between in survey and design

The difference between the in-survey and the design gives the volume of sand that is required in the reclamation, in order to finalize the project. The required information for this volume calculation is:

- Bathymetric survey
- Design drawings

6) Volume design

The volume that is calculated in step 5 has to be increased in order to compensate the losses that will be present (see paragraph 3.5, 7.1, 7.2 and 7.4). This volume is reduced by the already discharged volumes. These discharge volumes and area can be found in the daily reports. This volume is used in the sand balance (see paragraph 5.2 and paragraph 6.2).

7) Not enough sand available
There is not enough sand available when the volume required in the reclamation is larger than the volume of available sand in the MBA's. When this is the case a new MBA should be requested or a shallow draught TSHD should be mobilized (when shallow areas are present).

8) Request new MBA
When there is not enough sand available in the MBA, a new MBA should be requested. To investigate the quantity, quality and location of the sand a new soil investigation has to take place. To calculate the volume that is available in the new MBA, the following information is required:
- Multi-beam
- Regional geology
- Seismic
- Vibrocores
- Lab results

9) Shallow draught TSHD
When shallow areas are present in the MBA, a shallow draught TSHD can be mobilized to dredge these areas. The shallow draught TSHD removes a volume from this area's and makes the area accessible for the other TSHD's. This way more material can be extracted from the MBA's.

10) Tender production
In the tender phase there is calculated what productions can be achieved for each piece of equipment. During the execution of the project the productions should be on this level. This production figure is used in the tool: "Break even point" (see paragraph 5.4 and 6.4).

11) Production in MBA
As said before, the production in the MBA must be higher than the tender production, otherwise everything must be done to improve the production.
The volume that is extracted in each MBA is recorded in the daily reports. The extracted volume reduces the volume that is left in the MBA. This is recorded in the sand balance (see paragraph 5.2 and 6.2).
The soil investigation can be interpreted wrongly and this way a higher or lower volume can be extracted from the MBA. When this is the case the volume that is in the MBA should be reduced or increased by this volume.
The volumes that are extracted from the MBA are pumped into the reclamation area. The volume of the design should be reduced by the volume that is discharged; this is also part of the sand balance.

Required information in this phase, which can be found in the daily reports of the equipment:

- Discharged volumes
- Discharge areas
- Which marine borrow area the dredging took place

Required information that must be submitted by the crew:

- Experiences during the dredging process in the MBA, by the crew. About the quality and the production in a certain area

12) (Un)suitable/ (Un)dredgable volume

The soil investigation can be interpreted wrongly and this way a higher or lower volume can be extracted from the MBA. When this is the case the volume that is in the MBA should be reduced or increased by this volume.

13) Production is at maximum?

In this phase the production in the MBA is higher than the tender production. In order to get the production to a higher level; the production is compared to the productions in the past. When the production is at its maximum no action has to be taken. When the production is lower than the maximum; actions should be taken in order to improve the production.

Required information in this phase:

- Production figures from the past
- Production figures of the present

14) End date in trouble?

In this phase the production in the MBA is lower than the tender production. When the end date is in trouble, more equipment should be mobilized. Because the production is lower than the tender production, actions should be taken in order to improve the production.

Required information in this phase: The end date according to the contract

15) Mobilize more equipment

When the end date is in problem; more equipment should be mobilized. This is done in close deliberation with the head office.

Required information: Which equipment is available for the project.

16) Improve m^3/hour

When the production is lower than calculated the production should be improved. This can be done, by looking at the average TSHD cycle time (see paragraph 5.5 and 6.5). Then is known which phase of the dredging cycle can be improved. Also the discharge production has to be recorded (see paragraph 5.6 and 6.6). The discharge production gives information in order to reduce the discharge times. Also the drag head depth versus the TNO-layer gives information that can improve the production (see paragraph 5.3 and 6.3). By looking at the drawing is known where the material is. This way the dredge times can be reduced. The sampling of the inlet gives information about the coarseness of the material and can this can reduce the dredge times (see paragraph 5.1 and 6.1).

Required information in this phase:

- Dredge times	Daily reports
- Pumping and mooring times	Daily reports
- Sailing empty times	Daily reports
- Sailing full times	Daily reports
- Delays	Daily reports
- Discharge volumes	Daily reports
- Length of the pipeline	Daily reports
- Drag head depths	Log files
- TNO-layer	Soil investigation
- D_{50}	Lab results
- Percentage of fines	Lab results
- Coordinates of the drag head	Log files

4.2 Shooting script

In this paragraph the shooting script for BAM is given. The shooting script is divided into 5 steps. The steps are divided into several tasks that have to be executed in the order that they are mentioned. Behind each task a paragraph of this report is given. In this paragraph the required information for executing the task can be found. Step 1 and 2 should be finished before the start of the project. Step 5 should be done when the project is finished. The shooting script gives you the steps that have to be taken in chronological order. The shooting script, together with the BAM-plan gives you all the required steps and information to manage a MBA correctly. In figure 4.2a the shooting script is shown.

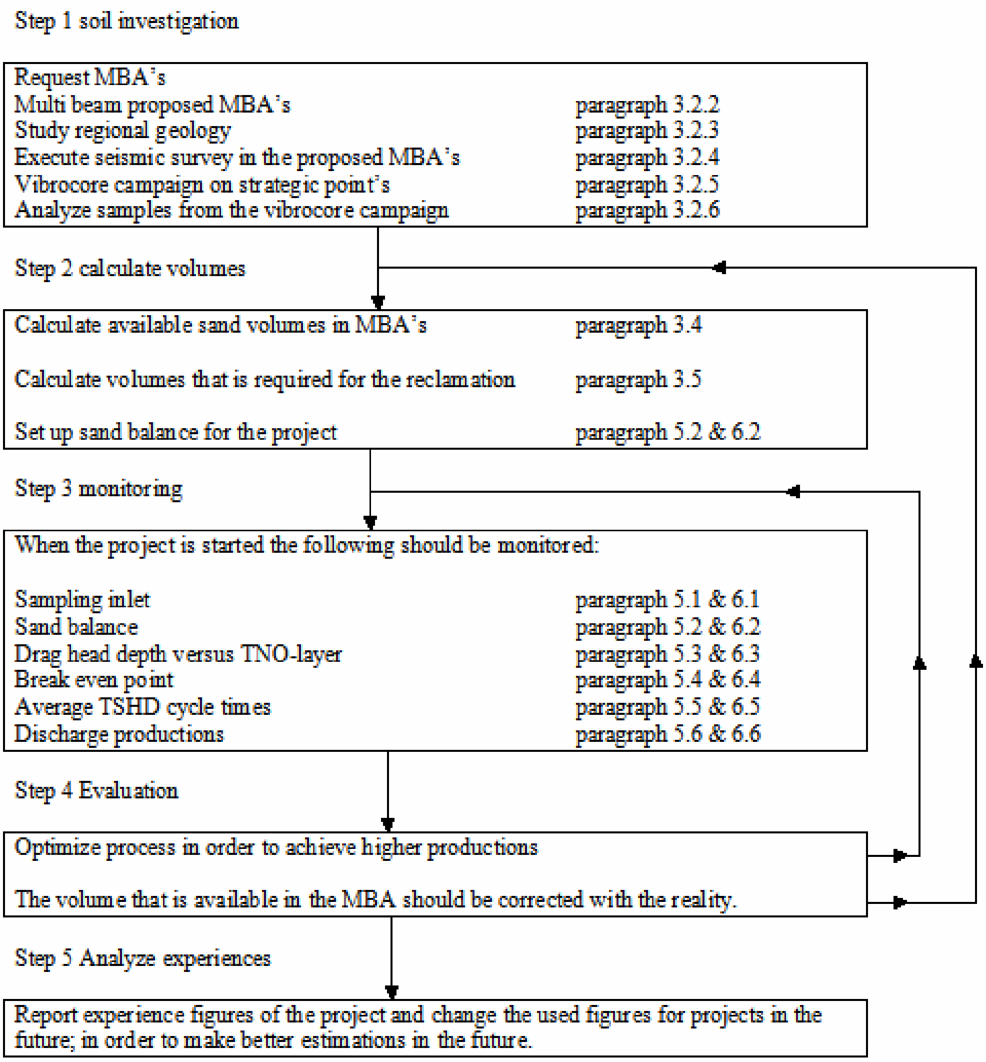


Figure 4.2a: The shooting script for BAM

5. Tools for BAM

In this chapter the monitoring of the marine borrow area is discussed. This is very important, because coming problems can be tracked in an early stage. This way precaution can be taken, to prevent the upcoming "problem". Monitoring is also important because you can see where you are in a project. During the graduation period certain tools for BAM were developed, which are mentioned in this chapter. The tools can help to improve the production. In this chapter a short description of the tools is given. In the next chapters the tools are further explained and analyzed.

5.1 Sampling inlet

The SI gives a rough picture about the quality of the material that is available in the MBA's. When starting to dredge in a new MBA it is recommendable to take samples from the inlet of the TSHD, especially when the seabed is very heterogenic. This method is a very quick and cheap method to investigate the quality of the material. With the results action can be taken in order to improve the production and the quality of the material in the sand fill. This should be done until a clear picture of the material is developed. The results of the samples that are taken on the NBNT-project can be found in Appendix 4.

5.2 Sand balance

Before the dredging work starts, it is important to set up a sand balance. In this balance there is monitored in which MBA the sand is removed and in which area of the project it is placed. It is very important that this is monitored, because in this way you know where and how much, material is present in the MBA's and how much is required for the reclamation.
The first thing that has to be done is comparing the material in the MBA with the volumes that are required in the reclamation. Weekly the sand balance should be updated. The volume in the particular MBA is deducted by the dredged volume in the MBA. The sand balance that is used on the NBNT project can be found in Appendix 5.

5.3 Drag head depth versus TNO-layer

The TNO-layer is the layer of sand that is available in the MBA's according to TNO. The sand balance gives an indication of volume that is left in the MBA's, but says nothing about the exact location of the material. The drag head depth can be found back in the VDMS data. When we compare the drag head depth with the seismic the exact location of the material can be seen. This way the TSHD's can dredge in the exact location where the material is left behind. The difference between the seismic and the suction depth is for the NBNT-project plotted on a drawing, which can be found in Appendix 6.

5.4 Break even point

Before the tender, the production calculations are made. During the project the productions of the equipment should be on this level. The tender production and the really achieved productions of the equipment should be compared with each other. This way the performance of the equipment can be verified. When the performance of the equipment is lower than tendered, an analysis should take place why this happened. It can be that the equipment is achieving lower productions, because of failures in the SI. At all times actions should be taken in order to improve the performance of the equipment, even when the equipments productions are above the tender production.

5.5 Average TSHD cycle times

To understand why productions of a TSHD go up or downwards it is recommendable to record the average cycle times of the TSHD's. By keeping up the cycle times there can be monitored which phase of the cycle becomes longer or shorter. This average cycle time should be made for each TSHD that is on site. With the result action can be taken in order to decrease the cycle times and with this increase the production.

5.6 Discharge production

TSHD's discharge the dredged material through a pipeline to the reclamation area. The discharge production depends on the length of the pipeline, the material that is discharged and the pump capacity. Coarse material like stones, shells and coarse sand are hard to discharge. In this tool the discharge distance is compared with the discharge production. This is done for all the TSHD's that are on site. With the result of this tool decisions can be made which TSHD should discharge on which pipeline in order to achieve higher discharge production. With this action the average cycle time will decrease which will lead to a higher production.

6. Elaboration of the tools

6.1 Sampling inlet

It is possible to take samples from the inlet about every 5 minutes. The time the sample is taken should be written down. This way the coordinates of the drag head can be found back in the VDMS file. This way the location where the sample was taken is known. The time on the used clock should be equal to the time of the VDMS.

Figures 6.1a,b,c,d: Samples from the inlet taken on the HAM 317

The samples are taken by throwing a metal bucket in the inlet, as illustrated by figure 6.1 a,b,c,d). This is done until the bucket is full the sample is pulled up and thrown into a plastic sample jar (see figure 6.1 d). After each sample the bucket is cleaned with water in order to get a clean next sample. The samples from the inlet are tested in the laboratory; here sieve curves are made from the samples. At the end a drawing is made with the quality of the samples that are taken. On the drawing the D_{50} and percentage of fines is plotted. The results of the sampling of the NBNT-project can be found in Appendix 4. The results are compared to the SI in chapter 7.3. The red samples on the drawing are unsuitable according to the schedule from paragraph 2.7.

With the results of the sample campaign a plan can be made where the dredging should take place in combination with the needs of quality on the sand fill and the length of the discharge pipe. When you look at the drawing you can see that some dredge areas contain coarse material and other dredge areas finer material. Dredge area 2009 contains finer material and dredge area 2209 contains coarser material. With the result decisions can be made where to dredge in order to achieve high productions or improve the quality.

6.2 Sand balance

The sand balance should weekly be updated by the volumes that are in the daily reports of the TSHD's. The volume of the design should be corrected with the site instructions that can take place during the project.

6.3 Drag head depth versus TNO-layer

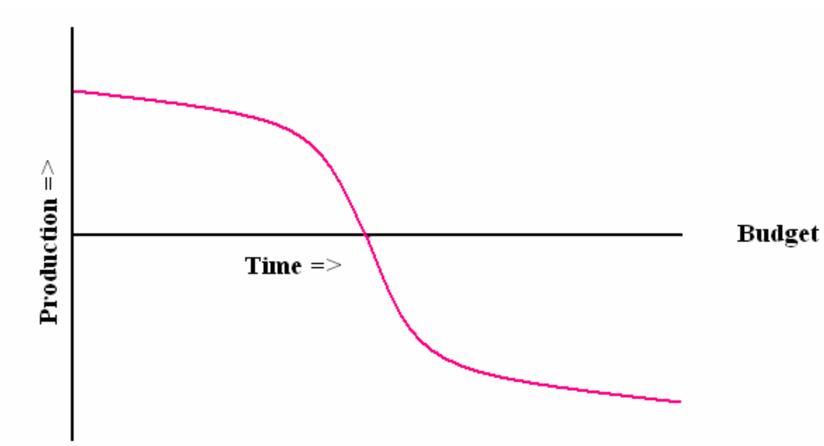
The depths of the drag head should monthly be plotted on the seismic. The drawing should be brought to the TSHD's, so the crew can see where the material is still present.

It can be that some areas that were assumed to be dredgable are undredgable. The volumes in the MBA in the sand balance can now be corrected by this volume.
It can also be that in some areas more material is removed than there was assumed to be possible by the seismic. The volume in the MBA in the sand balance can now be increased by this volume.

6.4 Break even point

When we look at TSHD's in a certain MBA, the following can be established, the productions will be in the beginning higher than when the MBA is almost empty. In the beginning the productions will be above the budget and will go downwards during the progress of the project. Productions go downwards because the sand layers become thinner and in some areas no material is left behind. The break even point is the point that the average production is equal to the budget.

It is important to record the production, and compare this production with the budget. When you put this in a chart, you will see something similar like Graph 6.4a that is displayed below.



Graph 6.4a: Instantaneous production of a TSHD in a certain borrow area

The horizontal line is the budget line. The production line is in the beginning above the budget line. On a certain moment the actual production line will go underneath the budget line. This is still no problem, because the average production is still above the budget line. Productions of a TSHD fluctuate more than this chart makes you believe. When you calculate the moving average, the line goes more and more fluently.

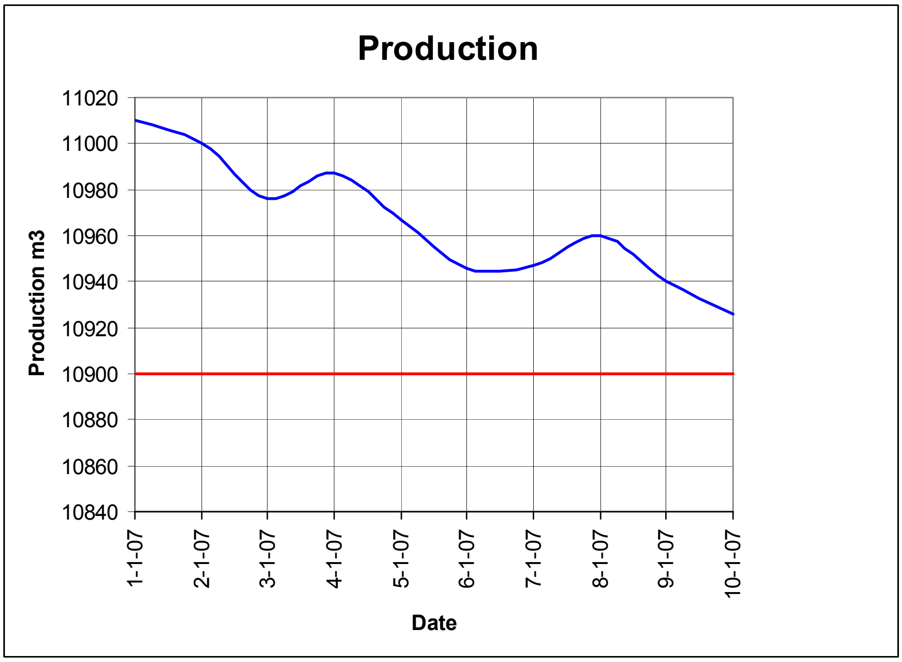
6.4.1. Calculation example

Previous productions of a TSHD was 1.100.000 m^3 in 100 days

Date	Production	Cumulative	Cumulative day	Moving average
01-01-2007	12000	1.112.000	101	11010
02-01-2007	10000	1.122.000	102	11000
03-01-2007	8500	1.130.500	103	10976
04-01-2007	12100	1.142.600	104	10987
05-01-2007	8900	1.151.500	105	10967
06-01-2007	8742	1.160.242	106	10946
07-01-2007	11120	1.171.362	107	10947
08-01-2007	12350	1.183.712	108	10960
09-01-2007	8800	1.192.512	109	10940
10-01-2007	9400	1.201.912	110	10926

Table 6.4a: Daily production figures of a TSHD

Let's say the budget production for this TSHD is 10.900 m^3 a day.
The average production (blue line) of the TSHD is coming closer to the budget production (red line), as shown by Graph 6.4b. The TSHD should improve its production before the production line crosses the budget line. This way higher productions will be achieved and the production line will stay above the budget production.



Graph 6.4b: Production that is going towards the budget production.

6.5 Average TSHD cycle times

To understand why productions go up or downwards it is recommendable to record the average cycle times of the TSHD's. By keeping up the cycle times there can be monitored which phase of the cycle becomes longer or shorter. This average cycle time should be made for each TSHD that is present on the project.

Following phases are used, when monitoring a TSHD on its performance:

Phase 1	Sailing empty.
Phase 2	Dredging.
Phase 3	Sailing full.
Phase 4	Pumping, mooring, unmooring and dumping (so the total time from arrival to the coupling point (CP) till departure from the CP.
Phase 5	Total delay (This is the total delay of the ship, with exception of bunkering and docking).

There are many types of delays which are displayed below. From all the delays only a few apply for BAM. The delays that apply for BAM are: Tide/draught, current and traffic delays.
It is important to dredge shallower areas first, in order to remove the material over here and make the areas accessible for the low tides. In order to decrease waiting time (because of a limited number of navigation channels and more the one TSHD) an extra channel can be created by a shallow draught TSHD. Important is that the direction of the navigation channel is in the same direction as the mainly present current direction. This way the TSHD is no moved sideward by the current and this way it will be easier to create the channel.

Environmental delays:	- Sea conditions
	- Repair due to waves
	- Current
	- Visibility
	- Tide draught
	- Traffic
	- Temperature/humidity
	- Pollution
Operational delays:	- Crew change/bunkering
	- Disposal area
	- Survey/positioning equipment
	- Auxiliary equipment
Technical delays:	- Suction pipeline/deck line
	- Hopper doors and deck
	- Hoisting winches and wire
	- Drag head(s)
	- Software/hardware
	- Wear and tear

Other deck related delays	- Floating pipeline - Submerged pipeline - Booster(s)
Engine rooms delays:	- Main engines - Auxiliary engines - Electrical installation - Hydraulic/pneumatic system - Propellers/rudders

The duration for each phase can increase because of deterioration and decrease because of improvements. Below all reasons for cycle time differences are mentioned.

Phase 1&3 Increases if
- The distance between the CP and the MBA increases, when dredging in a "new" MBA that is further away, or moving the CP further away from the MBA.

Phase 1&3 Decreases if
- The distance between the CP and the MBA decreases, when dredging in a "new" MBA closer to the site, or moving the CP closer to the MBA.

Phase 2 Increases if
- The layer thickness of the material is smaller.
- There are more fines in the dredged material.
- There are hard layers (rock, sandstone) on parts of the seabed.

Phase 2 Decreases if
- The layer thickness of the material is bigger, like when dredging in a new MBA.
- Heavy coarse material is dredged, like shells and coarse sand in the dredge area.
- No hard layers are found on the seabed.

Phase 4 Increases if
- Distance from CP to the sand fill increases.
- The material is coarser
- A booster is removed between the TSHD and the sand fill (taken from the view that the time that is won is bigger than the communication time that is required to start up).

Phase 4 Decreases if
- The distance from CP to sand fill area decreases
- The material consist of finer material
- A booster is installed between the TSHD and the sand fill

Phase 5 Increases if
- There are more delays, because of less CP's or when there is more traffic

Phase 5 Decreases if
- There are fewer delays, because of more CP's. There are also fewer delays when there are wider or more navigation channels.

6.5.1 Calculation example

On a day the HAM 309 made the following trips:

Action	Trip 1	Trip 2	Trip 3	Trip 4	Trip 5	Trip 6	Trip7
Dredge	60	55	45	65	55	60	70
Pumping, mooring, etc.	100	110	70	85	95	95	100
Sail empty	35	40	45	40	25	30	35
Sail full	45	60	45	35	35	50	50
Delay	0	0	20	0	0	10	15

Table 6.5a: The cycle times of the HAM 309

With this givens we can make an average for this day:

$$T_{dredge} = \frac{60+55+45+65+55+60+70}{7} = 59\,\text{min}$$

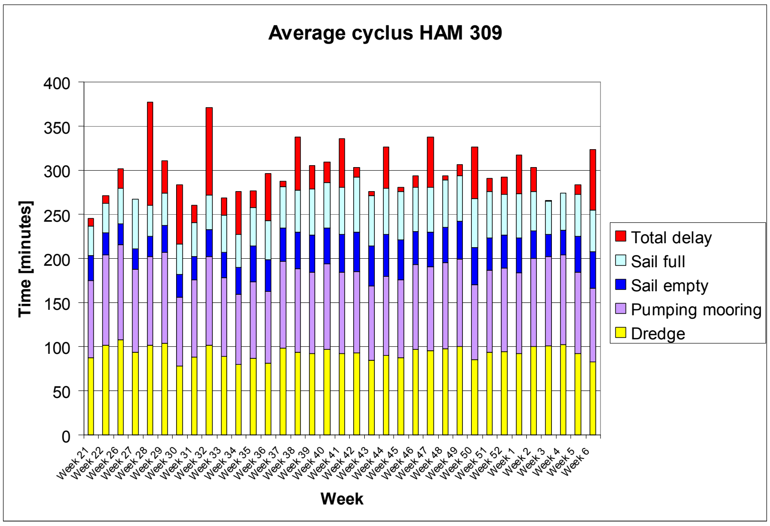
$$T_{pumping} = \frac{100+110+70+85+95+95+100}{7} = 94\,\text{min}$$

$$T_{sail,empty} = \frac{35+40+45+40+25+30+35}{7} = 36\,\text{min}$$

$$T_{sail,full} = \frac{45+60+45+35+35+50+50}{7} = 46\,\text{min}$$

$$T_{delay} = \frac{0+0+20+0+0+10+15}{7} = 6\,\text{min}$$

When you make a column, with these average times and compare the results with days or weeks before it would look something like the Graph on the next page.



Graph 6.5a: The average cycle times of the HAM 309 compared with each other

When the cycle time becomes longer and for that reason the productions reduce, action should be taken by looking at the graph. Immediately it is visible which phase took more or less time. You can try to compensate this by decreasing the cycle times with the actions that are mentioned in this paragraph

6.6 Discharge production

In this paragraph a calculation example is given and the results of the discharge productions of the NBNT-project are given.

6.6.1. Calculation example

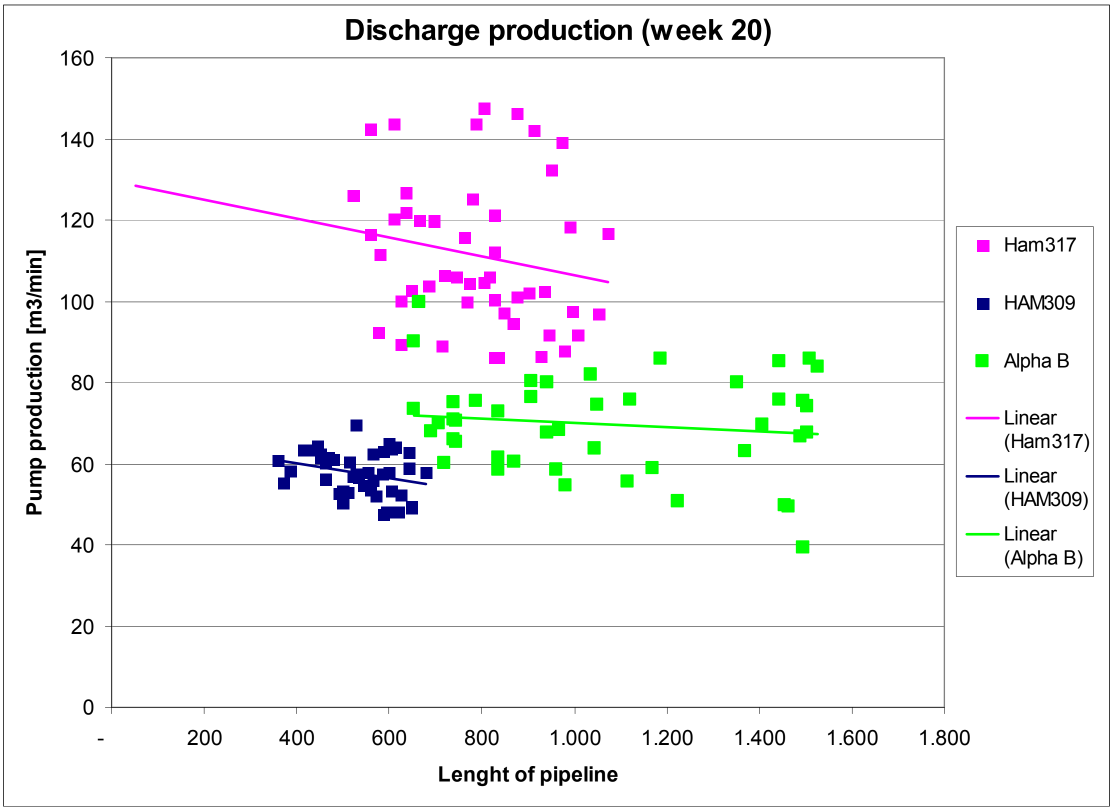
Trip of the HAM 317

Length of the pipeline	867 meter
Discharged volume	3400 m^3
Discharge time	55 min

Discharge production per minute = discharged volume / discharge time

Discharge production per minute = $\frac{3400}{55} = 62m^3 / \min$

When you do this for all the trips and make a graph from it you will get something similar as the graph that is shown on the next page. In this graph the length of the pipeline is set out against the discharge production. The graph that is shown is used on the NBNT project.



Graph 6.6a: The discharge productions of the TSHD's on the NBNT-project

As you can in Graph 6.6a, the Ham 317 achieves higher discharge productions than the other TSHD's. With this graph you can make decisions which TSHD should discharge on which coupling point, with its length of the pipeline.

7. Differences and analyses

In this chapter the following assumed will be checked for the NBNT-project:
- The total loss factor
- The loss factor, because of differences in density
- The efficiency of the MBA's
- The pollution and losses from the MBA
- The SI will be checked with the results of the samples that are taken

7.1 Loss factor on NBNT

Because the first phase of the NBNT project was finished; the volumes that are brought in can be compared to the volumes that were required. This way the assumed value of the 0,86 factor can be checked.

V_{design} =	10.159.317 m^3
$V_{brought\ by\ other}$ =	644.314 m^3
V_{needed} =	9.515.003 m^3
$V_{brought\ wet}$	11.341.810 m^3

$$V_{needed} = \left(V_{design} * \frac{1}{factor} \right) - V_{brought,by,other}$$

$$11.341.810 \quad = \left(10.159.317 * \frac{1}{factor} \right) - 644.314$$

Factor = 0,85 (compared to 0,86 assumed)

The factor is lower than previous assumed, so the losses on the NBNT-project are bigger than previous assumed.

$$"Losses" = \frac{1}{0,85} = 18\% \text{ (compared to 16\% assumed)}$$

The losses are larger than the losses that were calculated on previous projects in the Gulf region.
The losses are partly to explain to the difference in density in the hopper of the TSHD and the sand fill. The loss because of differences in density is calculated in the next paragraph.

7.2 Difference in density

In these paragraphs two different calculations are made to calculate the density in site the TSHD's hopper and are compared to the density of the sand fill.

7.2.1. Compared to other investigation

According to an investigation is the wet density in site the hopper equal to 2070 kg/m^3[**]. This density is measured on a project in Germany and can be different from the situation in Bahrain.

Dry density in reclamation:

On the NBNT-project the dry density is measured from the top 1,5 meter of the reclamation. The average in-situ dry density of the reclamation is 1612 kg/m^3. The results can be found in Appendix 7. The standard variation of the measurements is calculated below.

$$\sigma_n = \sqrt{\frac{\Sigma(X_i - \mu)^2}{n}} = \sqrt{\frac{(2017185)}{100}} = 142 kg/m^3$$

Grain density of TSHD sand:

The grain density is determined by the international laboratory services (ILS) in Bahrain. According to their measurement is the grain density of the hopper sand equal to: 2575 kg/m^3. The results can be found back in Appendix 8. The standard variation of the measurements is calculated below.

$$\sigma_n = \sqrt{\frac{\Sigma(X_i - \mu)^2}{n}} = \sqrt{\frac{(9676)}{6}} = 40 kg/m^3$$

Water density:

The water density is determined on the NBNT-project. This is done by putting 1 liter of seawater in a container which is weighted. This is done 5 times and this had the following results: 1028, 1026, 1025, 1028 and 1028 kg/m^3. The average water density over these samples is 1027kg/m^3. The standard variation of the measurements is calculated is calculated below.

$$\sigma_n = \sqrt{\frac{\Sigma(X_i - \mu)^2}{n}} = \sqrt{\frac{(8)}{5}} = 1{,}26 kg/m^3$$

[**] Uitlevering van zand, bepaling van de relatieve dichtheid

Calculation of the wet density in the reclamation:

Assume that the sand in site hopper of the TSHD is fully saturated, so $V_{air} = V_{water}$

$$V_{grain} = \frac{\rho_{situ}}{\rho_{grain}} * 100\% = \frac{1612}{2575} * 100\% = 62{,}60\%$$

$$V_{pores} = 100\% - V_{grain} = 100\% - 62{,}60\% = 37{,}40\%$$

$$G_{water} = V_{water} * \gamma_{water} = 0{,}374 * 1027 = 384kg$$
$$G_{grain} = V_{grain} * \gamma_{grain} = 0{,}6260 * 2575 = 1612kg$$
$G_{total} = 1612 + 384 = 1996$ kg/m^3

Variation on calculation, because of differences in situ density that is measured:
$\mu - \sigma_n = 1612 - 142 = 1470$ kg/m^3 $\gamma_{sat} = 1911$ kg/m^3
$\mu + \sigma_n = 1612 + 142 = 1754$ kg/m^3 $\gamma_{sat} = 2081$ kg/m^3

Variation on calculation, because of differences in grain density that is measured:
$\mu - \sigma_n = 2575 - 40 = 2535$ kg/m^3 $\gamma_{sat} = 1986$ kg/m^3
$\mu + \sigma_n = 2575 + 40 = 2615$ kg/m^3 $\gamma_{sat} = 2006$ kg/m^3

Variation on calculation, because of differences in water density that is measured:
$\mu - \sigma_n = 1027 - 1{,}26 = 1025{,}74$ kg/m^3 $\gamma_{sat} = 1996$ kg/m^3
$\mu + \sigma_n = 1027 + 1{,}26 = 1028{,}26$ kg/m^3 $\gamma_{sat} = 1996$ kg/m^3

Table 7.2a gives the possible deviation of the wet density in the reclamation.

Failure	*Change wet ρ-situ (%)*
ρ-situ	4,4
ρ-grain	0,5
ρ-water	0

Table 7.2a: Failure table

According to this calculation, the density in the hopper of the TSHD is higher than in the reclamation area. This is seams to be impossible, because the material just settles in site the hopper of the TSHD. The material on the reclamation is compressed by heavy bulldozers and has more time to settle than in the TSHD's hopper. Because of this question marks are put to the hopper density of 2070 kg/m^3.

The sand in Germany is not equal to the sand in the gulf region. On the next page the characteristic of the two types of sand are given and is given what is the effect of the characteristics on the density.

Germany:
- Quartz sand
- Well rounded
- Well sorted
- “high” grain density

Gulf region:
- Calcareous sand
- Angular shaped
- Well graded (with shells)
- “low” grain density

Calcareous sand gives a lower cone resistance than on quartz sand, when a cone penetration test (CPT) is executed. This way the measured density of quartz sand is higher.
Angular shaped sand has a higher volume of pores than well rounded sand. This way the density of well rounded sand is higher.
Well sorted sand has a higher volume of pores than well graded sand. This way the density of well graded sand is higher.
Calcareous sand has a various grain density (2550-2750 kg/m^3). This way the density of quartz sand (2650 kg/m^3) can be higher or lower. On the NBNT-project the grain density of calcareous sand was 2575 kg/m^3.

	CPT-friction	CPT-friction	Well-rounded	Angular shaped	Well sorted	Well graded	Density
Germany	+		+		-		+/-
Gulf region		-		-		+	+/-

Table 7.2b: The influence of the characteristics on the density

The density of the sand from Germany gives a higher hopper density, because of the difference in sand characteristics as displayed in Table 7.2b.

7.2.2. Compared to the displacement

In this paragraph the hopper density is calculated by using the difference in displacement of the vessel. The difference in displacement before and after dredging compared with the load gives the density in the hopper.[††]

Before the dredging starts there is a layer of water present inside the hopper. This load is measured by sensors above the hopper that measure the load. Also the displacement is measured by pressure sensors underneath the ship.

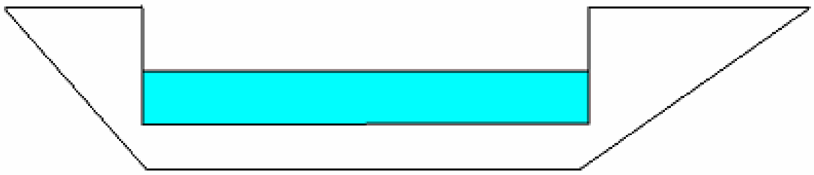


Figure 7.2a: TSHD before dredging

$$G_{ship} = Displacement - y_{water} * load$$

After dredging the hopper is filled with saturated sand.

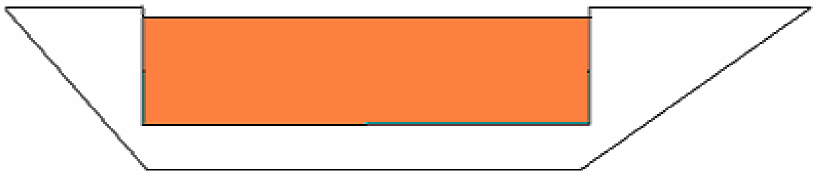


Figure 7.2b: TSHD after dredging

$$G_{load} = Displacement - G_{ship}$$

The volume of the load is measured with the sounding, so the hopper density can be calculated with the following formula:

$$\rho = \frac{M}{V}$$

Example:

Trip 1329 of the HAM 317	
Displacement before dredging	6470 ton
Water density	1027 kg/m^3
Load before dredging	2447 ton
Displacement after dredging	10877 ton
Volume after dredging (from sounding)	3722 m^3

[††] VOUB deel 6, procesmeting en automatisering

G_{ship} = 6470 – (1,027 * 2447)
G_{ship} = 3957 ton

G_{load} = 10877 – 3957 = 6920 ton

$$\rho = \frac{6920000}{3722} = 1859 kg/m^3$$

For all the Van oord TSHD's the hopper density is calculated. The results can be found in Appendix 9. The average hopper densities of the TSHD's are mentioned below.

HAM 317	Average hopper density = 1798 kg/m^3
HAM 309	Average hopper density = 1920 kg/m^3
HAM 312	Average hopper density = 1802 kg/m^3

Average hopper density of the TSHD's = 1840 kg/m^3
Measurements on earlier projects in the Gulf show that the average density in the TSHD's hopper is equal to 1810 kg/m^3, which is almost similar to the result of the calculation that is made on the NBNT-project.

Loss factor for differences in density = $((\frac{2032}{1840}) - 1) * 100 = 10\%$

This calculation seems to be close to the reality. The total losses were 18 %.

$\frac{10}{18} * 100 = 56\%$ percent of the total losses are caused by differences in density.
The other 44% of the losses are caused by the other reasons that are mentioned in paragraph 3.5

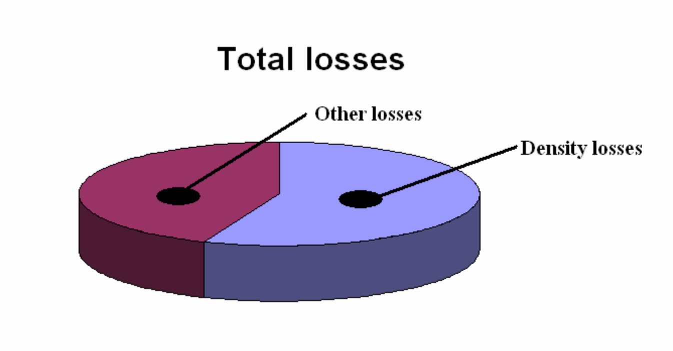


Figure 7.2c: The partition of the losses

7.3 MBA efficiency

In a few MBA's the quality and dredge efficiency went to a lower level and according to the SI almost all the suitable material was removed from the MBA. Because of this these MBA's were named empty, but there is still some material present in these areas. This material can technically be won, but not on an economical manner. Now the efficiency of the MBA can be calculated. In Table 7.3a the calculated volumes and the volumes that are really dredged are displayed.

MBA	Calculated volume [m3]	Dredged volumes [m3]	MBA efficiency [%]
3	529.000	1.170.210	221
5	3.977.000	4.399.021	111
6	887.000	1.464.908	165
Total	5.393.000	7.034.139	130

Table 7.3a: Efficiency of the MBA

The efficiency of the MBA's together is higher than expected, namely 30 percent higher than expected before. Noticed must be that the difference in efficiency between the MBA's is big.

MBA 3 is almost completely empty, only along the outer boundaries of the MBA some material is left (see Appendix 6). This material is very difficult to remove, because the current will move the TSHD and it will be forced out of the MBA. The material is technical gain able, but not on an economical manner. The TSHD has longer dredging times and this results in a lower production.

MBA 5 can be divided into four areas. The first area is the south of MBA 5; here a hard layer of calcarenite is present. The SI said that there would be sand. The area is undredgable. The second area is the east of MBA 5 (dredge area 2105, 2106); here very fine material is present with a high concentration of H_2S. H_2S is in high concentrations deadly. During some trips measurements were executed on board to measure the concentration of H_2S. This resulted in the fact that it was to dangerous to dredge in this areas. Third area is the west side of MBA 5; here the area is very shallow. This volume is not in the volume from MBA5 in Table 7.3a, because the shallow volumes were registered separately. The fourth area is the north; here a lot of material is removed. Even below the TNO-layer. In this area a lot of over dredging took place. After a while the quality of the fill material became worse and there is decided to not dredge in this area anymore.
The undredable areas in the east and the south made the MBA efficiency lower.

MBA 6 is almost completely empty. In some areas some material is still present, but other areas are completely empty. The sand that is still present can technical be removed, but not on an economical way. During the project the dredging time in MBA 6 became longer and is decided to stop dredging in MBA 6.

MBA 3 has the largest efficiency. The MBA is close to the CP and with this it doesn't matter if the dredging times increase, because the total cycle time will be similar when dredging in another MBA. This way most of the material could be removed.

MBA 5 has the lowest efficiency. Here some areas were undredgable and a smaller volume could be extracted from the MBA, this decreased the efficiency of the MBA.

The volume that is available for the reclamation was higher than expected, so the reduction factors that are mentioned in paragraph 3.4 were too conservative.
One reduction factor is that only a maximum layer of two meters can be extracted from the MBA. In some areas of the NBNT-project 5,5 meter of material is removed. In these areas there were hardly any stones/rocks in the seabed, so the dredging could continue in an economical way. Also the 50 percent recoverability is very conservative, because in MBA 3 almost all material has been extracted from the MBA.

The efficiency is strongly depending on the material that is present in the MBA. The SI is not giving a perfect picture of what kind of material is present in the MBA. In MBA 5 the material was totally different than the SI did predict.

MBA 6 has also a high efficiency but is lower than the efficiency of MBA 3. The distance between the MBA and CP is longer. This way it is not economical to remove all the material, because longer sailing times and longer dredging times will lead to a lower production.

7.4 The pollution and the losses in the MBA

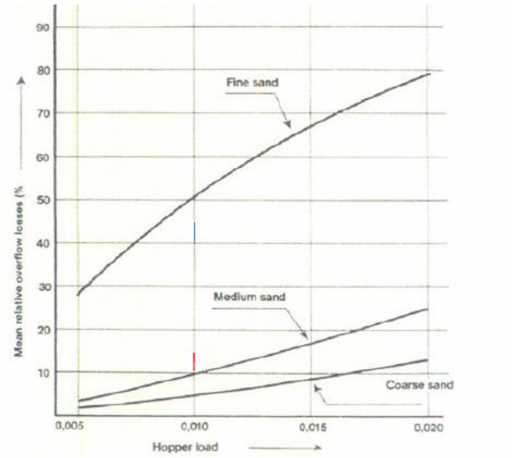
In this chapter is investigated if the MBA gets polluted with fines and if there is material disappearing out of the MBA. Part of the dredged material disappears by the means of overflow back in the water column. Here the material settles on the seabed. Part of the material will stay in the MBA and another part of the material is taken outside the MBA by the current, where it settles. The pollution and the losses have got a lot to do with each other, because the material from the overflow will settle in the MBA (pollution) or the material will disappear from the MBA (losses).

7.4.1 Pollution of the MBA

On the NBNT-project is investigated if the MBA gets polluted with fines. The more there is dredged in a certain area the finer the material will become on the seabed, because fine material that disappears by the means of overflow will settle on the seabed. The samples that are taken from the inlet should consist more fine material during the time. In Appendix 10 the percentage of fines is set out to the production in a certain area. Only areas where "a lot of samples" are taken are displayed. Also a graph with all the results is displayed. The samples in dredge areas 2109, 2206, 2209 and the total graph doesn't show an increase in fines. Dredge areas 2207 and 2208 show a slightly increase in percentage of fines. It can be that the fines disappear out of the MBA, which is investigated in the following paragraph.

7.4.2 Losses from the MBA

The losses from the MBA will be investigated in this paragraph. First will be examined what amount of material disappears out of the overflow. With this information is calculated which fractions and which volume disappears out of the MBA.
There are different mathematical models to calculate the amount of overflow. One of them is a very simple but very useful method. The method is called Verbeek, 1984. On base of the discharge (Q) the length (L) and the breadth (B) of the TSHD's hopper and the type of sediment a picture can be created of the amount overflow.



$$Hopperload = \frac{Q}{L * B} \qquad [m/\sec]$$

Graph 7.4a: Estimating method of the average percentage of overflow

In Table 7.4b the classification of the types of sand is given. On the NBNT-project the average fraction diameter is 370 μ. This means that the sand is medium to fine sized. The dimensions of the hopper of the different TSHD's that are on site are shown in Table 7.4c.

Sand type	Fraction diameter
Coarse sand	0,6 – 2 mm
Medium sand	0,2 – 0,6 mm
Fine sand	0,063 – 0,2 mm

Table 7.4b: Classification of sand[‡‡]

TSHD	Length hopper [m]	Breadth hopper [m]
HAM 309	48,04	11,4
HAM 312	41	11,5
HAM 317	39,2	12,8
Alpha B	45	15

Table 7.4c: The dimensions of the hopper

The discharge inside the hopper is equal to the discharge of the suction pipe for the 312 and the 317. For the 309 and the Alpha B the discharge in the hopper is two times the discharge of the suction pipe, because these TSHD's have two suction pipes installed.

<u>HAM 309</u>
Average suction speed 5,13 m/s
Diameter of the 2 suctions pipes = 800 mm

$$Q = v * A = v * \frac{1}{4} * \pi * D^2 * 2 = 5{,}13 * \frac{1}{4} * \pi * 0{,}8^2 * 2 = 5{,}16 m^3 / \sec$$

$$Hopperload = \frac{Q}{L * B} = \frac{5{,}16}{48{,}04 * 11{,}4} = 0{,}0094 \qquad [m / \sec]$$

<u>Ham 317</u>
Average suction speed 6,17 m/s
Diameter of the suction pipe = 900 mm

$$Q = v * A = v * \frac{1}{4} * \pi * D^2 = 6{,}17 * \frac{1}{4} * \pi * 0{,}9^2 = 3{,}93 m^3 / \sec$$

$$Hopperload = \frac{Q}{L * B} = \frac{3{,}93}{39{,}2 * 12{,}8} = 0{,}0078 \quad [m / \sec]$$

‡‡ VOUB part 1

<u>Ham 312</u>
Average suction speed 6,03 m/s
Diameter of the suction pipe = 900 mm

$$Q = v * A = v * \frac{1}{4} * \pi * D^2 = 6{,}03 * \frac{1}{4} * \pi * 0{,}9^2 = 3{,}84 m^3 / \sec$$

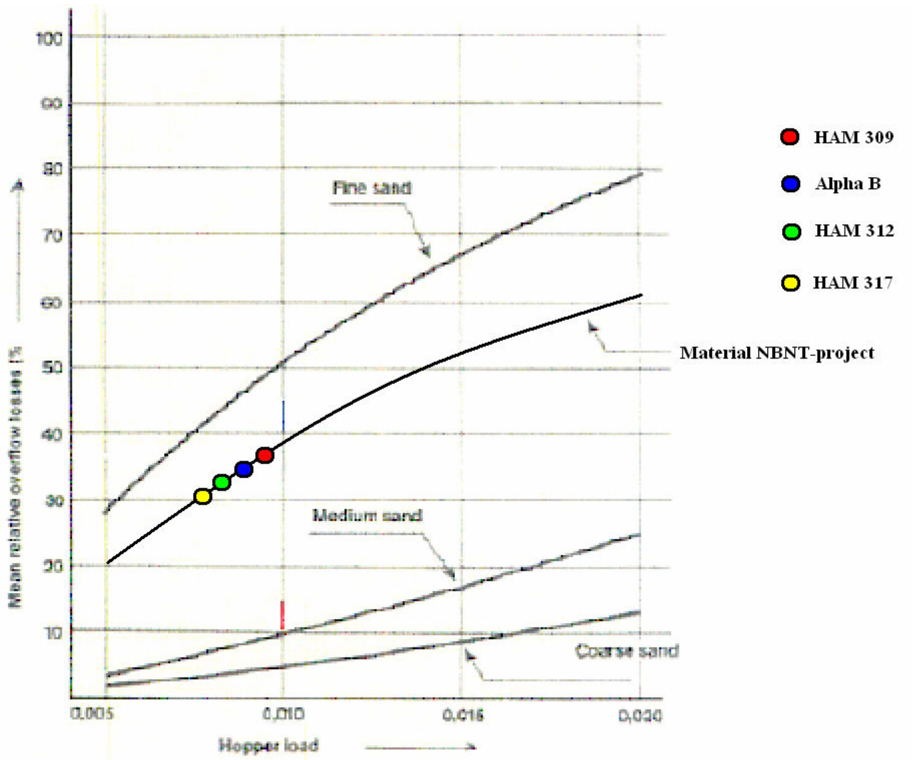
$$Hopperload = \frac{Q}{L * B} = \frac{3{,}84}{41 * 11{,}5} = 0{,}0081 \qquad [m / \sec]$$

<u>Alpha B</u>
Average suction speed 6 m/s
Diameter of the 2 suction pipes = 800 mm

$$Q = v * A = v * \frac{1}{4} * \pi * D^2 * 2 = 6 * \frac{1}{4} * \pi * 0{,}8^2 * 2 = 6{,}03 m^3 / \sec$$

$$Hopperload = \frac{Q}{L * B} = \frac{6{,}03}{45 * 15} = 0{,}0089 \qquad [m / \sec]$$

In the graph below the overflow losses of the different TSHD's is showed. The working line for the material that is present on the NBNT project is also displayed in the graph.



Graph 7.4d: Percentage of overflow for the TSHD's on the NBNT-project

Overflow losses of the TSHD's according to Verbeek, 1984:

HAM 309	37%
Alpha B	35%
HAM 312	33%
HAM 317	31%

On one trip samples are taken from the overflow; Every 10 minutes 1 liter of mixture was taken from the overflow and thrown in one and the same plastic sample jar. The sample is considered as an average particular size distribution of the material that flows overboard. A hydrometer test is executed on the sample and the results can be found back in Appendix 11.

Several samples are taken on one and the same trip, because one sample is not representative for the entire trip. In the beginning only very fine material will disappear by the means of overflow. At the end of the trip the distance between the settled material and the water surface is small and the velocity will be higher. At the end of the trip more coarse material will disappear by the means of the overflow.

The material that disappears from the overflow will settle over a certain area. The fall velocity can be calculated with the formula of Stokes.

The formula of Stokes:
$$v = \frac{D^2 * (\frac{\rho_g - \rho_w}{\rho_w}) * g}{18\eta}$$

D =	The particular size of the fraction	[m]
ρ_w =	The water density	[kg/m^3]
ρ_g =	The grain density	[kg/m^3]
g =	The gravitational force	[m/sec^2]
η =	kinematical viscosity	[m^2/sec]
v =	velocity	[m/s]

$\eta = 1 * 10^{-6}$ m^2/sec (water with a temperature of 20 °C)
$\rho_w = 1027$ kg/m^3
$\rho_g = 2727$ kg/m^3
$g = 9{,}81$ m/s^2

Fraction [mm]	Average fraction [mm]	Percentage [%]	Fall velocity [mm/sec]	Falling time for 10 meters	Horizontal distance [m]
1,18 – 0,6	0,89	2,5	715	14 seconds	3
0,6 – 0,425	0,5125	0,7	237	42 seconds	11
0,425 – 0,3	0,3625	2,4	119	84 seconds	21
0,3 – 0,15	0,225	11,9	46	219 seconds	55
0,15 – 0,075	0,1125	29,4	11	15 minutes	219
0,075 – 0,05	0,0625	40,1	3,5	47 minutes	709
0,05 – 0,02	0,035	4	1,1	3 hours	2.262
0,02 – 0,01	0,015	3	0,2	14 hours	12.316
0,01 – 0,005	0,0075	1,5	0,05	2,3 days	49.265
0,005 – 0	0,0025	5,5	0,006	21 days	443.389

Table7.4e: Fraction and fall velocity

The horizontal distance that is covered is based on a current velocity of 0,5 knots/hour. The average loss through the overflow is 34 percent. Part of this percentage will fall back in the MBA. Another part and especially the finer material will cover a large horizontal distance and will disappear from the MBA.
It is very impossible to calculate the volume that will disappear from the MBA, because it is strongly dependent on the current velocity, the direction of the current, the depth of the water column, the material and the place in the MBA were the material falls back into sea.

Total volume that has to be dredged: 37.722.405 m^3
Volume that flows overboard: 12.825.618 m^3 (34% of the total volume)

In Table 7.4f is displayed which volume flows overboard and where this volume will end up. For example fraction 0,0625 mm: 5.143.073 m^3 that flows overboard will settle in an area with a radius of 709 meter from where the TSHD was at that moment.

Average fraction [mm]	Percentage [%]	Total volume [m^3]	Horizontal distance [m]
0,89	2,5	320.640	3
0,5125	0,7	89.779	11
0,3625	2,4	307.815	21
0,225	11,9	1.526.249	55
0,1125	29,4	3.770.732	219
0,0625	40,1	5.143.073	709
0,035	4	513.025	2.262
0,015	3	384.767	12.316
0,0075	1,5	192.384	49.265
0,0025	5,5	705.409	443.389

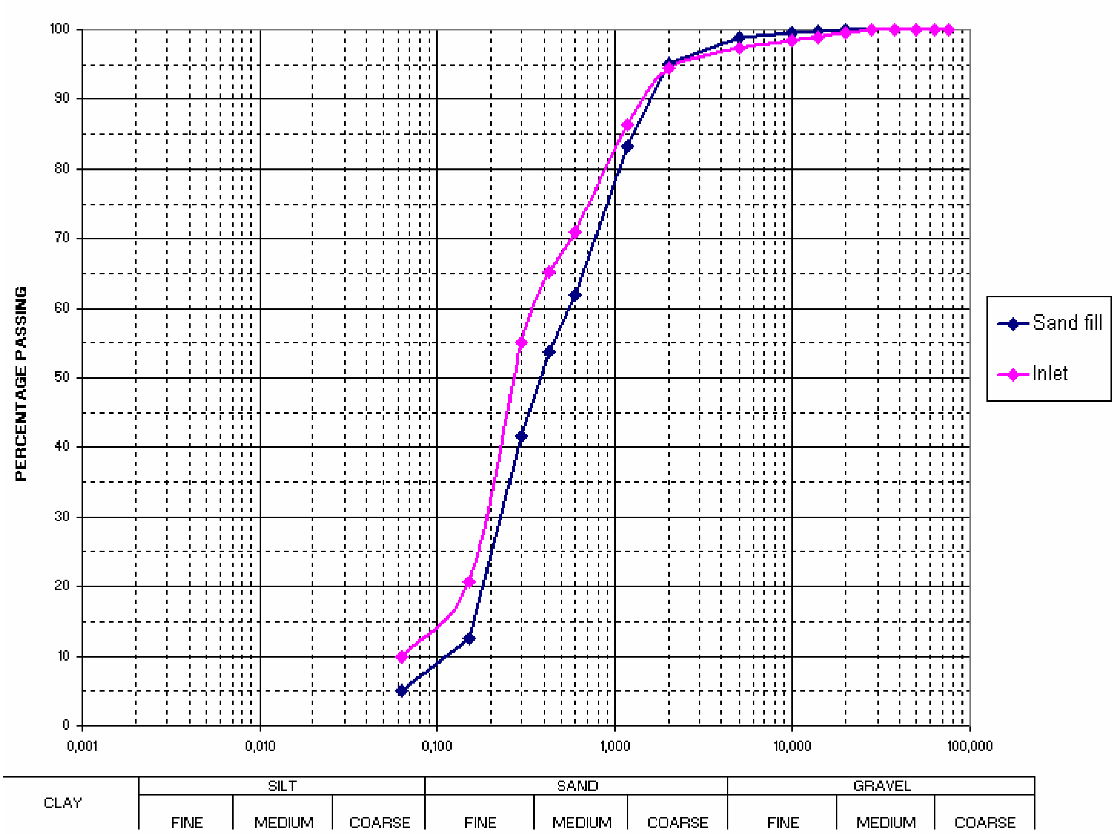
Table 7.4f: Where the overflow fractions are landing

7.4.3 Conclusion

The distance between the west of MBA 9 and the east of extension 1 is around 14 kilometers. The current velocity on the NBNT-project varies from 0 to 3 knots. Proven is that a part of the material will disappear from the MBA, especially the finer fractions. This explains why no MBA pollution takes place on the NBNT-project.

7.5 Quality improvement

Earlier is said that a TSHD can improve quality of the material by the means of overflow. This is investigated on the NBNT-project. 12 samples are taken from the inlet on the manner that is explained in paragraph 6.1. Also 4 samples are taken from the sand fill. This is done on the same manner as mentioned before, but the bucket is moved into the flow by an excavator (for safety reasons) until the bucket was filled with the mixture. The samples are sieved and the results are combined for the inlet and the sand fill. The result is displayed in Graph 7.5a.



Graph 7.5a: The sieve results of the inlet and the sand fill together

The material from the inlet has a higher content of fines than the material on the sand fill. The quality is improved, because of the overflow that took place. The percentage of fines was lowered by 5 percent. Also the Sample from the sand fill contains less coarse material. This can be explained by the de-fragmentation that takes place in the pipeline. Shells experience friction with the pipeline and de-fragmentize during the discharge process.

7.6 Inlet samples compared to the SI

In this paragraph the SI will be compared to the samples that are taken from the inlet. Because of the heterogenic seabed the vibrocores will only be compared with the sample that is taken the closest to the location of the vibrocore. This is done for all vibrocores from extension 1 (The approved new MBA). The drawing with the location of the vibrocores can be found back in Appendix 12. The results of the comparison can be found back in Appendix 13. The conclusion of the comparison is that most of the results from the vibrocores are similar to the results of the samples that are taken from the inlet and so the working method is correct.
Because the very heterogenic character of the seabed there are some differences.

8. Results

The loss factor on the NBNT-project was higher than expected, namely 18 percent (instead of 16 percent).

Part of the losses can be explained by the differences in density. 10 percent of the material gets lost because of differences in density.

The MBA efficiency was 30 percent higher than calculated on the NBNT-project.

The MBA didn't get polluted with fines, because the fine fractions that run overboard were taken away by the current.

Quality improvement takes place inside the TSHD, because a part of the fines disappear through the overflow. The friction between the pipeline and the material causes de-fragmentation of the material, this way less coarse material was found on the sand fill. Sampling the inlet is a good manner to map the quality of the MBA's

9. Difference analyses

In this chapter the differences between the SI and the in really dredged material will be discussed. In paragraph 9.1 all the differences are given. In paragraph 9.2 the possible explanation for the differences are given

9.1 Differences

1. The TSHD's dredged deeper than was supposed to be possible in MBA 5.
2. Overall more material is removed than was supposed to be possible.
3. A lower percentage of fines is found in the reclamation.
4. There is no MBA pollution noticed.
5. The losses are bigger than expected.

9.2 Possible explanations

1. The suction head broke through a layer of calceranite and a layer of sand was exposed by the means of this. This layer of calceranite was interpreted as a layer that was impossible to break through. The force of the drag head and the jets opened the layer and exposed the sand layer.

2. The assumed for the volume calculation was too conservative. Especially the maximum dredge layer of 2 meters is very conservative. Also the 50 percent recovery is very conservative. In most of the MBA's almost all the material is removed.

3. The percentage of fines in the reclamation is lower because the TSHD's improved the quality by the means of overflow.

4. Large amounts of fines disappear out of the MBA. The finer material that flows out of the overflow is taken out of the MBA by the current. The propeller of the TSHD also loosened the finer material from the seabed in shallow areas. This material is also taken away by the current. Before the dredging starts there is already a plum of material visible behind the TSHD and this proves that the process takes place.

5. It can be that the old ground level has settled. In the beginning of the project bulldozers removed the top layer of the seabed; hereby a layer of clay was exposed. It can be that this layer has been settled under the pressure of the material that is placed on top.

10. Conclusion and recommendations

The result of the graduating period is a shooting script that can be used for all dredging projects in the future. Even when the project is not in the gulf region, the shooting script can be useful to follow. Mentioned must be that the factors that are used in the gulf region are not equal to the factors that has to be used in other areas of the world.

On the NBNT-project the TSHD’s have been working as economical as possible in the marine borrow areas. Borrow area management is a very difficult strategic analyzes, which depends on an endless amount of factors. The result of how the TSHD’s has been set in is not mentioned in the report, but daily the planning was adjusted in order to get the productions as high as possible.

This document is especially helpful to support projects where the supply of sand is limited. This document can help foresee upcoming problems, which has to do with borrow area management. So anticipation on the problems can take place on time. This anticipation will result in a minimization of time and costs.

The volume that was available according to the soil investigation was lower than the really dredged volumes in the marine borrow areas. The reduction factors that were used were too conservative. The reduction factors that are used are different for all projects. This way it is important to look at the conditions of the project in order to make better volume estimations.

Always be conservative about the amount of sand that is available in the MBA’s. This way you prevent the project will come in problems in a later stage and more time is available to solve the problem.

When a new project is started it is important to record all the movements of the material from the beginning. This includes: The area where it is excavated, the area where it is dumped and the volume of the transported material. This applies for the dry as well as the wet transported material.

Place the revetment as soon as possible, because the rocks will reduce the erosion of the slopes. This is especially important on places were the current is strong and the waves can attack the slope. With this action the losses will be reduced.

Dredging should take place in the shallow areas as soon as possible, this way the material underneath will be exposed and the area will be available during the low tides. This way you prevent the production to become dependant on the high tides.

When the available volumes are calculated, the MBA’s close to the CP should be given a higher efficiency; because of the short sailing times it is acceptable that the dredging times are higher. MBA’s further away from the CP should be given a lower efficiency for the same reason.

Divide the project in smaller parts. This way the marine borrow area can be managed better. When one part of phase is finished the loss factor can be re-calculated for the specific project.

At the beginning of the project it is better to use the “conservative” factor 0,85 in stead of 0,86; when calculating the volume that is required to finalize the project.

Material with a large amount of fines should be pumped in a large sand fill, in order to prevent high losses. When the distance between the pipe and the water box is large; then the material has more time to settle. In a large sand fill the fine material will spread over a large area and will form a thin layer, this is mostly acceptable. The material with a large amount of fines can also be pumped in a small sand fill; this way the quality of the material will improve, but the losses through the water box will be high.

When the TSHD is almost full it is recommendable to dredge in an area where the material is coarse. This way the amount of material that disappears by the means of overflow will be reduced.

In order to reduce the traffic delays on projects with more than one TSHD, a channel can be created. This way the TSHD don’t have to wait on each other when there is only one channel. When making a channel with a shallow draught TSHD make sure that the direction of the present main current is equal to the direction of the channel. This way the TSHD is not moved sideward. This way it is easier to create the channel.

It is important to involve the crew in the planning, this way the crew gets the opportunity to give their view on borrow area management and better decisions can be made. When this is done; the crew will be more motivated to execute the job.

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Seek, and ye shall find

Guidance for borrow area management

Appendix

Index

Appendix 1 (equipment)

TSHD’s

HAM 317

Length:	97,50 m
Breadth:	18,40 m
Draught:	7,12 m
Hopper capacity:	4.407 m^3
Maximum dredging dept:	37,10 m
Speed loaded:	13,20 kn

HAM 309

Length:	124,10 m
Breadth:	19,63 m
Draught:	6,49 m
Hopper capacity:	4600 m^3
Maximum dredging dept:	33,00 m
Speed loaded:	14,20 kn

HAM 312

Length:	94,85 m
Breadth:	17,02 m
Draught:	5,68 m
Hopper capacity:	3512 m^3
Maximum dredging dept:	30,00 m
Speed loaded:	11,40 kn

Alpha B		
	Length:	112,00 m
	Breadth	21,40 m
	Draught	6,40 m
	Hopper capacity:	4737 m^3
	Maximum dredging dept:	30,00 m
	Speed loaded:	13,70 kn

CSD

HAM 217		
	Length:	88,45 m
	Breadth	16,80 m
	Draught	3,80 m
	Maximum dredging dept	23,00 m

Appendix 2 (vibrocore)

Boskalis Westminster – Van Oord JV

North Bahrain New Town Project

Borehole Logsheet

Employer : **Housing & Urban Development Committee**
Engineer : French Town Planning
Main contractor : Boskalis Westminster - Van Oord JV
Project : **North Bahrain New Town**

Date tested : 20/okt/06
Equipment : Vibrocore
Logger : Tito

Borehole no. **118**
Sample location : 0
Easting : 438467.37
Northing : 2902791
In-survey : 0.00
Soil level : 0.00
CPT location match : 0

Depth (m)	Legend	Sample Nr	elevation (m)	Description	Thicknes s (m)	% < 63 um
0.0			0.00	0		
0.25		1	-0.25	light brown med to coa SAND with calcarentie frag (sample: 0.20-0.30)	0.4	0%
0.50 – 1.75		2	-0.50 – -1.75	grey fi SAND with sandstone frag (sample: 0.65-1.53)	1.35	0%
1.75 – 1.90		0		pale white SILT STONE	0.15	0%
2.00 – 4.00			-2.00 – -4.00			
REMARKS:				**Total:**	**1.90**	

Appendix 3 (sieve result)

Boskalis Westminster – Van Oord JV

North Bahrain New Town Project

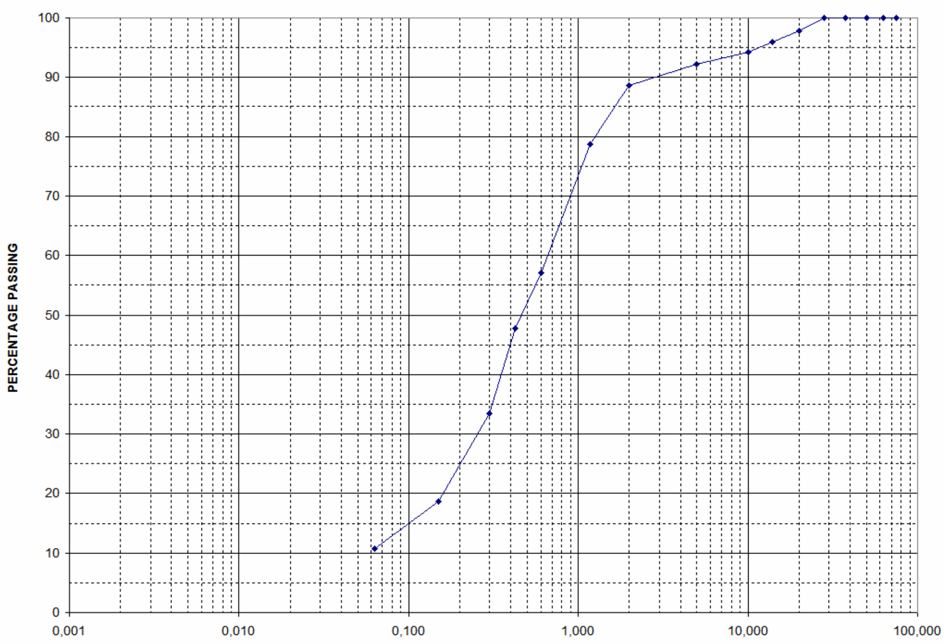
Particle Size Distribution

Employer	**Housing & Urban Development Committee**	**Sample ID:**	28046
Engineer	French Town Planning	Sample location:	HAM 317
Main Contractor	Boskalis Westminster - Van Oord JV	Depth:	
Project	**North Bahrain New Town**	Easting:	
Laboratory specimen description:		Northing:	

Particle Size Distribution Results

Particle Size (mm)	75,0	63,0	50,0	37,5	28,0	20,0	14,0	10,0	5,00	2,00	1,18	0,600	####	####	0,150	####
Percent Passing	100	100	100	100	100	97,8	95,9	94,3	92,2	88,7	78,7	57	47,8	33,5	18,7	10,7

D50	0,462	mm
D10	#####	mm
D90	2,811	mm



CLAY	SILT			SAND			GRAVEL			COBBLES
	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	

0,002 0,006 0,02 0,06 0,2 0,6 2 6 20 60

PARTICLE SIZE (mm)

Sample by	PDB	Date	Remark	Standard: BS 1377 part 2
Tested by	AL HOTTY	Date		

Appendix 4 (Sample results)

Appendix 5 (sand balance)

Progress of Works NBNT per 29 April 2007

Borrow Area's

Area	Estimated Volumes	Done until 29/4/7	To go after 29/4/7	% Progress
MBA1a				
MBA1b				
MBA1c				
MBA1d				
MBA1e				
MBA2				
Total	13.772.592	13.016.536	756.056	95%

Area	Estimated Volumes	Done untill 29/4/7	Available after 29/4/7	MBA Efficiency
MBA2	250.000	4.090	245.910	2%
MBA3	529.000	1.170.210	-641.210	221%
MBA4	2.824.000	1.987.579	836.421	70%
MBA5	3.977.000	4.435.999	-458.999	112%
MBA6	887.000	1.464.908	-577.908	165%
MBA7	140.437	140.437	0	100%
MBA8	517.000	399.208	117.792	77%
Shall. 4-5-7	2.850.000	496.389	2.353.611	17%
Shall.3	500.000	0	500.000	0%
EXT 1	6.102.000	1.750.265	4.351.735	29%
MBA14	705.240	0	705.240	0%
MBA15	1.046.296	0	1.046.296	0%
Total	20.077.973	11.844.995	8.232.978	59%

Area	Estimated Volumes	Done untill 29/4/7	To go after 29/4/7	% Progress
Palm Gr. Ch.	1.085.000	870.188	214.812	80%
Grand Bay	1.833.900	1.762.694	71.206	96%
Channel 1	200.000	0	200.000	0%
Channel 2	300.000	63.075	236.925	21%
Channel 3	300.000	0	300.000	0%
Fisherm. Ch.	450.000	87.639	362.361	19%
Total Dry	4.168.900	2.783.596	1.385.304	67%
Suitable	2.968.900	1.986.596	982.304	67%
Unsuitable	1.200.000	797.000	403.000	66%
Total Suitable	36.819.465	26.848.127	9.971.338	73%

Equipment

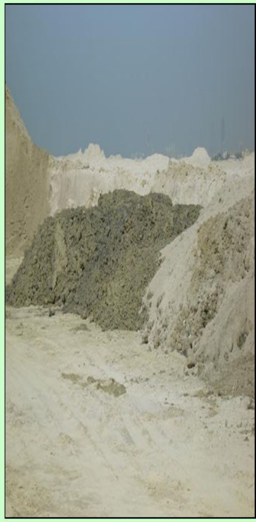
Equipment	Done
Ham 217	8.553.713
Cyrus	4.462.823
Total	13.016.536

Equipment	Done
HAM 309	5.145.371
HAM 317	4.903.554
Apha B	1.241.725
HAM 312	549.973
Total	11.290.650

Equipment	Done
Dry	2.783.596
Total Total	27.090.782

Reclamation

Inclusive beaches and hills
Exclusive, the green areas



Reclamation Island	Total Net	Total Net dry	Done Dry	Total Net wet	Total Wet Gross	Done Wet Gross	To do Wet Gross	% Completed
Island 3	3.459.876	0	0	3.459.876	4.023.112	1.701.145	2.321.967	42%
Island 4	2.546.891	0	0	2.546.891	2.961.501	1.994.341	967.160	67%
Island 7	401.380	0	0	401.380	466.721	162.380	304.341	35%
Island 8	3.014.747	0	0	3.014.747	3.505.520	1.124.267	2.381.253	32%
Island 9	7.314.479	312.500	0	7.001.979	8.141.836	4.648.692	3.493.144	57%
Island 10	4.470.527	312.500	0	4.158.027	4.834.915	2.400.253	2.434.662	50%
Island 11	2.297.047	312.500	0	1.984.547	2.307.613	2.043.204	264.409	89%
Island 12	976.471	312.500	0	663.971	772.059	85.460	686.599	11%
Island 13	3.217.604	1.415.889	769.314	2.448.290	2.846.849	2.121.115	725.734	75%
Island 14	6.941.713	485.000	-125.000	7.066.713	8.217.108	9.220.695	-1.003.587	112%
Backfill channel 10	361657	0	0	361.657	420.531	0	420.531	0%
Backfill TB 9	272876	0	0	272876	317.298	0	317.298	0%
Total	35.275.268	3.150.889	644.314	33.380.954	38.815.063	25.501.552	13.313.511	66%

Appendix 6 (drag head depth versus TNO-layer)

Appendix 7 (dry density in reclamation)

Boskalis Westminster – Van Oord JV

North Bahrain New Town Project

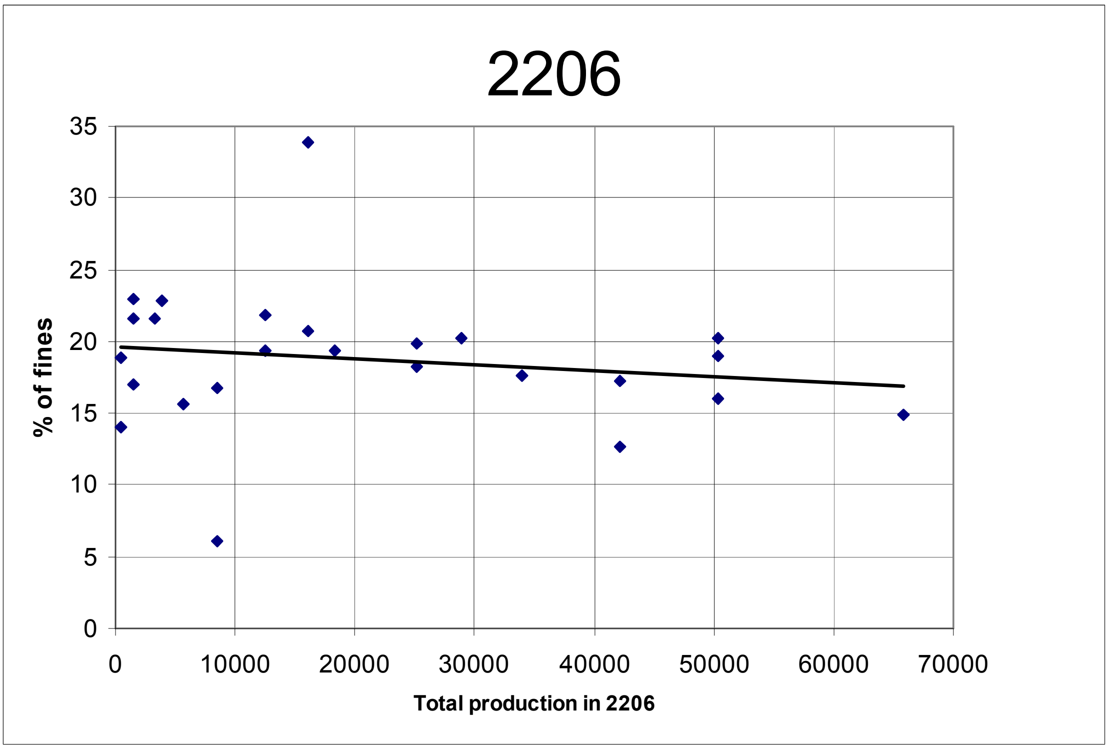
Average IN-SITU density:		**1612**	**kg/m3**
Location	**IN-SITU density**	**Location**	**IN-SITU density**
island 14a	1845	island 14a	1587
island 14a	1781	island 14a	1634
island 14a	1700	island 14a	1550
island 14a	1532	island 13c	1533
island 14a	1504	island 13c	1508
island 14a	1709	island 13b	1499
Island 13a	1859	island 13b	1433
Island 13a	1656	island 13b	1433
island 14a	1536	island 13b	1398
island 14a	1713	island 13b	1468
island 14a	1661	island 13b	1428
island 14a	1609	Island 14a	1437
island 14a	1657	Island 14a	1420
island 14a	1568	Island 14a	1376
island 14a	1661	Island 14a	1443
island 14a	1608	Island 14a	1383
island 14a	1520	Island 14a	1360
island 14a	1751	Island 14a	1636
island 14a	1503	Island 14a	1481
island 14a	1579	Island 14a	1339
island 14a	1903	Island 14a	1506
island 14a	1677	Island 14a	1462
island 14a	1642	Island 14a	1465
island 14a	1686	Island 14a	1434
island 14a	1492	Island 14a	1196
island 14a	1521	Island 14a	1362
island 14a	1743	Island 14a	1450
island 14a	1626	Island 14a	1414
island 14a	1495	Island 14a	1610
island 14a	1676	Island 14a	1581
island 14a	1545	island 14a	1608
island 14a	1517	Island 10	1836
island 14a	1688	Island 10	1806
island 14a	1608	Island 10	1816
island 14a	1748	Island 10	1712
island 14a	1711	Island 10	1785
island 14a	1560	Island 10	1773
island 14a	1581	Island 10	1768
island 14a	1680	Island 10	1829
island 14a	1591	Island 10	1827
island 14a	1670	Island 10	1788
island 14a	1702	Island 10	1767
island 14a	1580	Island 10	1740
island 14a	1504	Island 10	1627
island 14a	1619	Island 10	1604
island 14a	1703	Island 10	1835
island 14a	1715	Island 10	1801
island 14a	1631	Island 10	1805
island 14a	1599	Island 10	1780
island 14a	1687	Island 10	1780

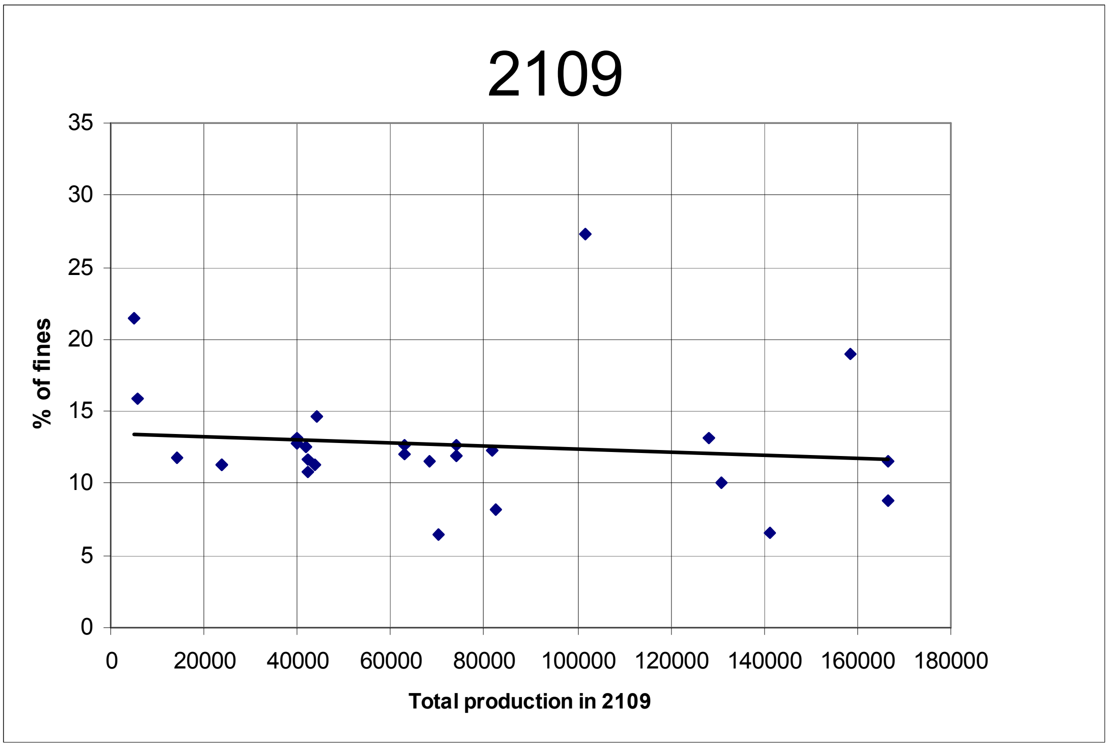
Appendix 8 (grain density)

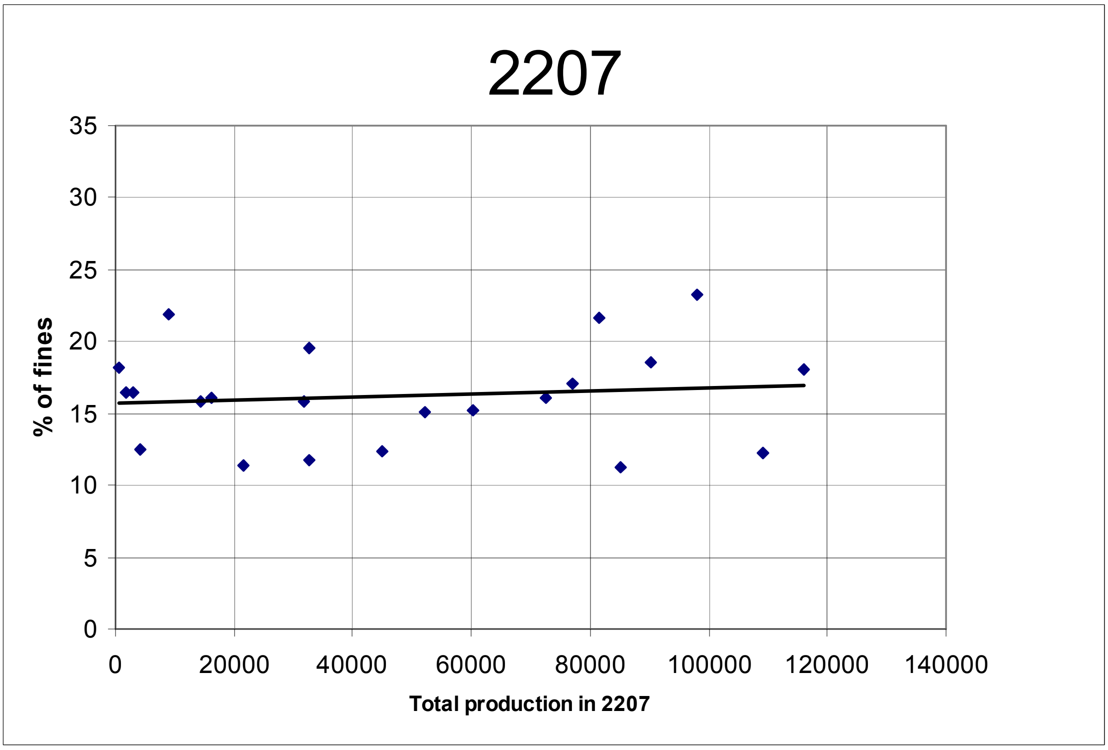
Appendix 9 (hopper density)

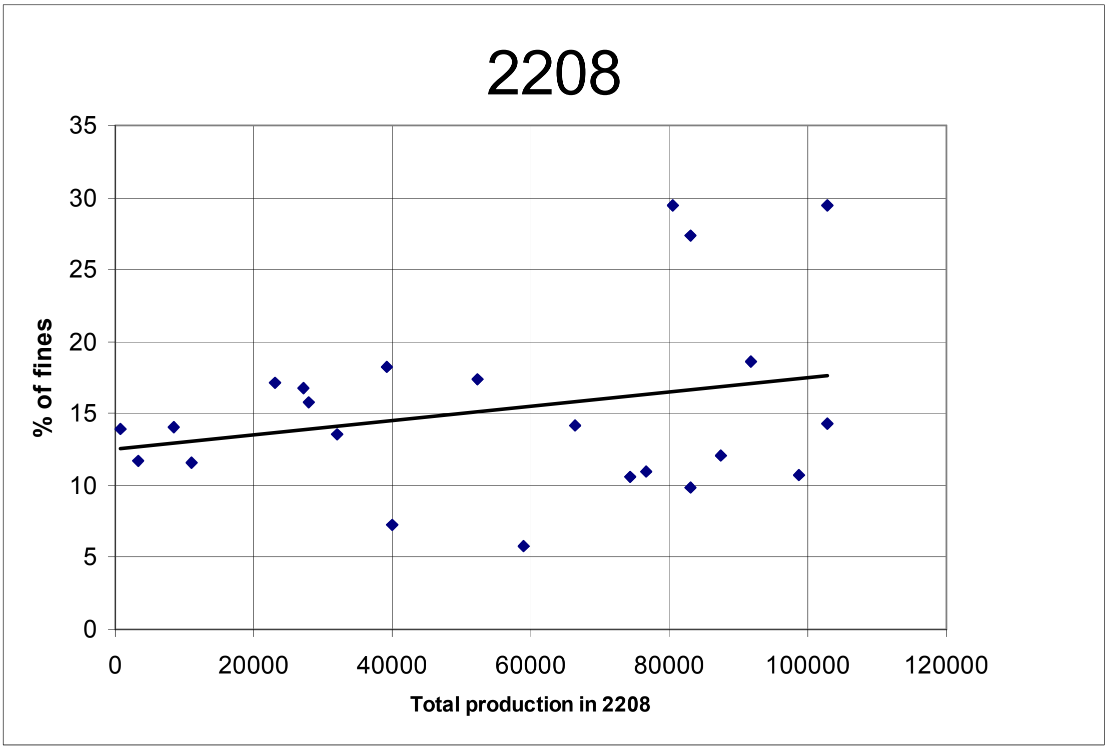
Ship	Trip	Dis after	Dis before	Ywater	Load	Volume	Rho hoppe	Average	Total average
317	1329	10877	6470	1,027	2447	3722	1859		
317	1330	10965	5811	1,027	1734	3782	1834		
317	1331	10273	6074	1,027	2044	3431	1836		
317	1332	10154	5790	1,027	1678	3240	1879		
317	1333	10915	6321	1,027	1900	3736	1752		
317	1334	10377	5777	1,027	1535	3629	1702		
317	1335	10211	6814	1,027	2681	3407	1805		
317	1336	10482	4960	1,027	868	3597	1783		
317	1337	10540	5988	1,027	1708	3643	1731	1798	
309	1528	11844	6854	1,027	1763	3514	1935		
309	1529	11825	6687	1,027	1685	3535	1943		
309	1530	11644	7043	1,027	2401	3608	1959		
309	1531	11773	7774	1,027	2725	3487	1949		
309	1532	11840	7793	1,027	2832	3487	1995		
309	1533	11630	8128	1,027	3040	3630	1825		
309	1534	11682	7750	1,027	2814	3651	1869		
309	1535	11431	6292	1,027	1363	3603	1815		
309	1537	11830	8012	1,027	3166	3551	1991	1.920	
312	143	7776	4082	1,027	792	2414	1867		
312	145	7702	3717	1,027	135	2225	1853		
312	146	7734	3688	1,027	131	2390	1749		
312	147	7759	3807	1,027	323	2453	1746		
312	148	7871	4058	1,027	643	2463	1816		
312	149	7855	3616	1,027	148	2361	1860		
312	150	7694	5374	1,027	1675	2390	1690		
312	151	7799	3769	1,027	252	2385	1798		
312	153	7899	3654	1,027	214	2429	1838	1802	1840

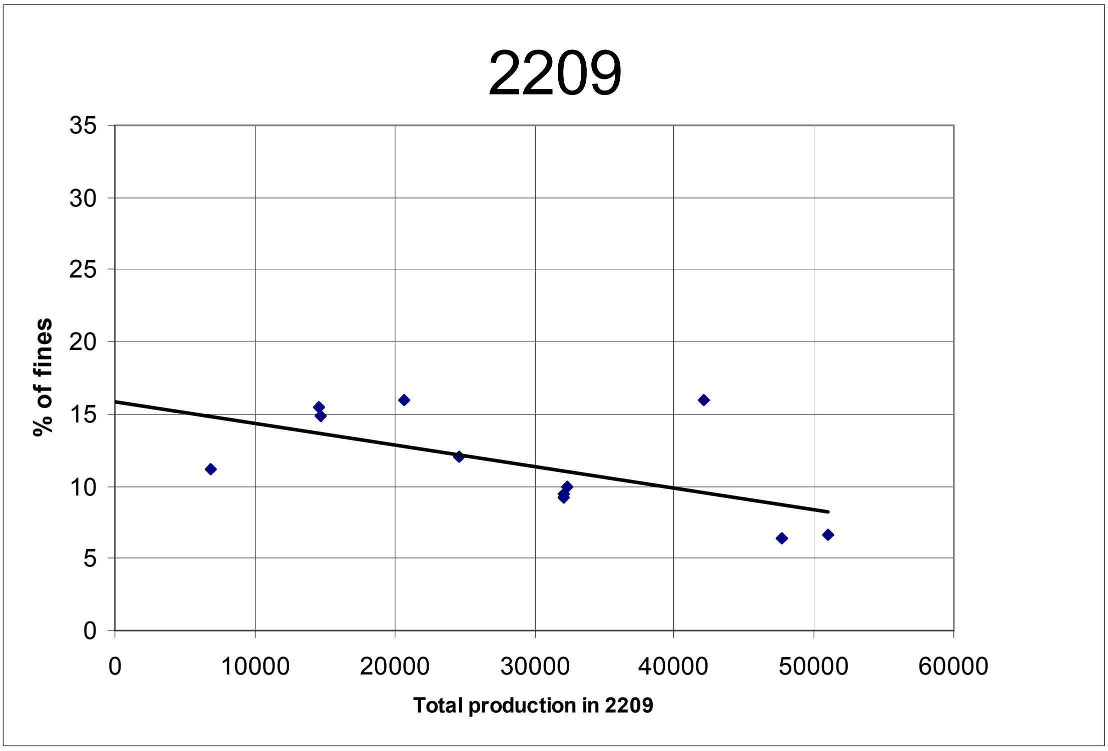
Appendix 10 (percentage of fines versus production)

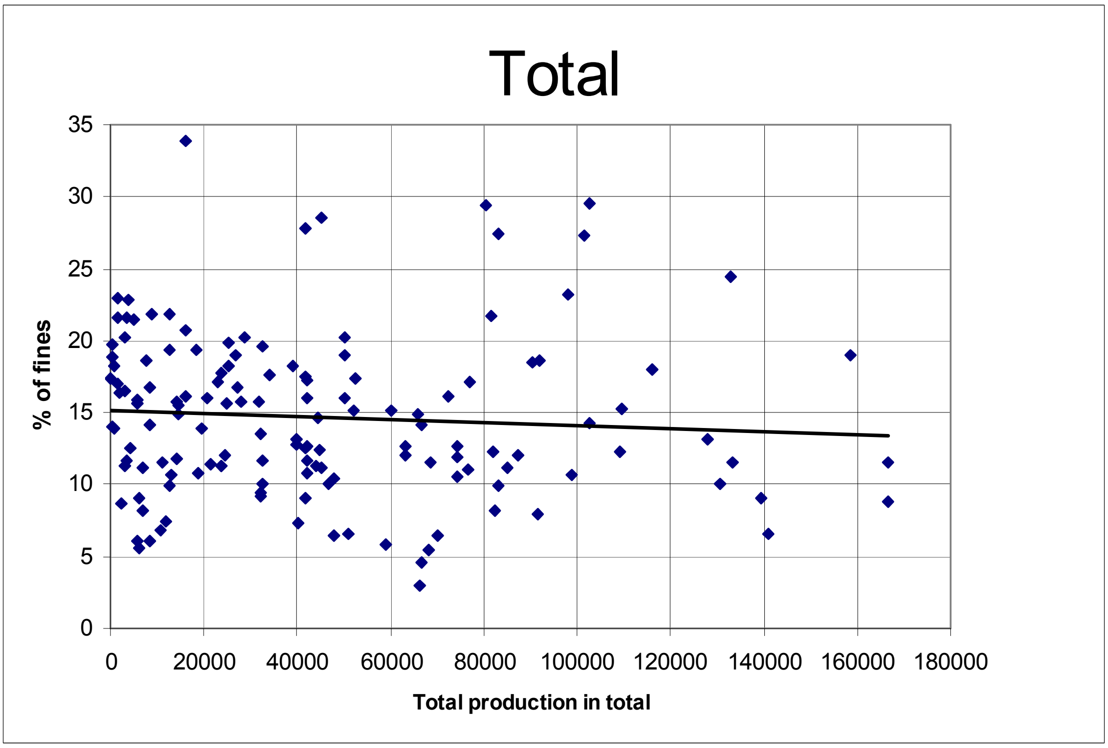



2109
35
30
25
20
15
10
5
0
% of fines
0
20000
40000
60000
80000
100000
120000
140000
160000
180000
Total production in 2109


2207
35
30
25
20
15
10
5
0
% of fines
0
20000
40000
60000
80000
100000
120000
140000
Total production in 2207


2208
35
30
25
20
15
10
5
0
% of fines
0
20000
40000
60000
80000
100000
120000
Total production in 2208


2209
% of fines
Total production in 2209
0
5
10
15
20
25
30
35
0
10000
20000
30000
40000
50000
60000


Total
% of fines
Total production in total
0
5
10
15
20
25
30
35
0
20000
40000
60000
80000
100000
120000
140000
160000
180000

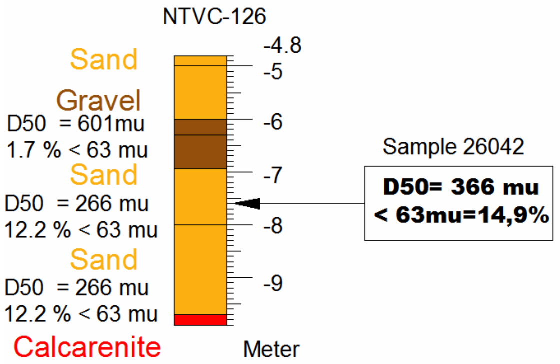
Appendix 11 (average particular size distribution)

Appendix 12 (location of the vibrocores and samples)

Appendix 13 (comparison of the samples versus vibrocores)

NTVC-126 versus Sample 26042
Distance between samples: 66 meter
Depth: 7,6 m-NSD

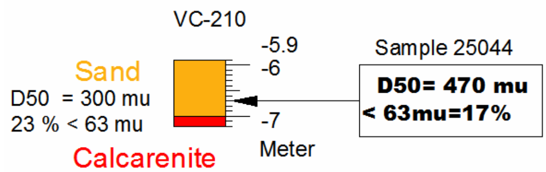
	%-fines	D_{50}
NTVC-126	12,2	266
Sample 26042	14,9	366



The samples look almost similar to each other, although the amount of fines and D_{50} of the sample from the inlet are slightly higher. The material from the inlet is coarser; this can be because some material from the gravel layer is left behind or mixed with the layer underneath.

VC-210 versus Sample 11036
Distance between samples: 60 meter
Depth: 6,7 m-NSD

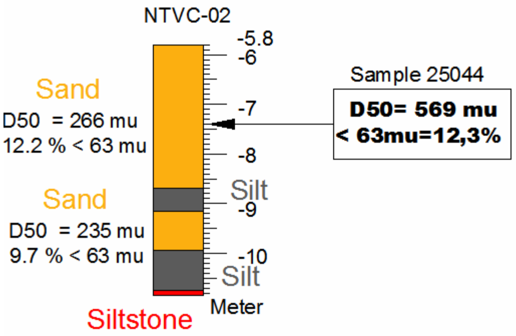
	%-fines	D_{50}
VC-210	23	300
Sample 11036	17	470



The sample from the inlet is a little bit coarser. The other samples from the inlet show that more to the north the samples are getting coarser and the amount of fines decreases. Sample 11036 is situated 45 meters more to the north as VC-210 and this can be the explanation for the difference between the samples.

NTVC-02 versus Sample 25044
Distance between samples: 88 meter
Depth: 7,4 m-NSD

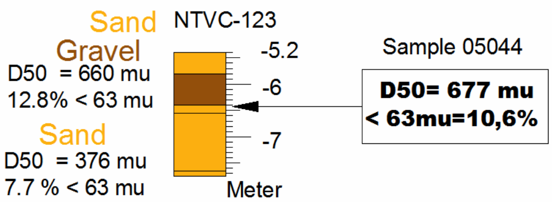
	%-fines	D_{50}
NTVC-02	12,2	266
Sample 25044	12,3	569



The amount of fines of the samples is equal to each other, but the D_{50} of the vibrocore is significantly lower. It can be that this layer of the vibrocore is of coarser material. The sample from the vibrocore has a length of 2,9 meter and is not divided into smaller samples. Possible is that some layers are coarser and that other layers exist out of finer material.

NTVC-123 versus Sample 05044
Distance between samples: 48 meter
Depth: 6,41 m-NSD

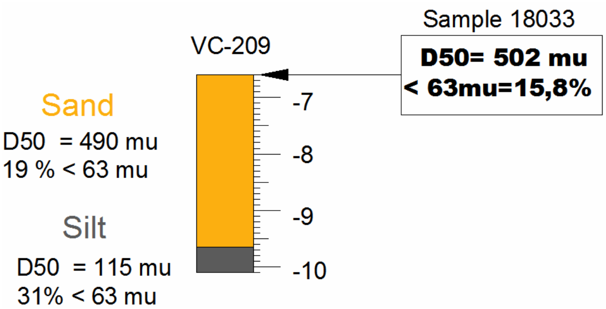
	%-fines	D_{50}
NTVC-123	7,7	376
Sample 05044	10,6	677



Because the sample from the inlet is taken on a depth of 6,41 meter it falls just outside the gravel layer from the vibrocore. It seems that the top layer of the sand from the vibrocore contains gravel fragments from the layer above.

VC-209 versus Sample 18033
Distance between samples: 100 meter
Depth: 6,6 m-NSD

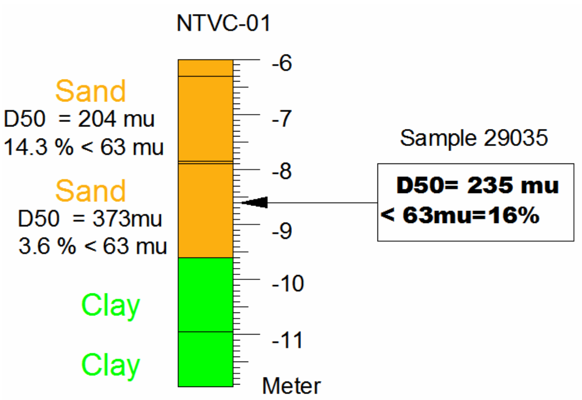
	%-fines	D_{50}
VC-209	19	490
Sample 18033	15,8	502



The samples are giving similar results with hardly any other values.

NTVC-01 versus Sample 29035
Distance between samples: 22 meter
Depth: 8,6 m-NSD

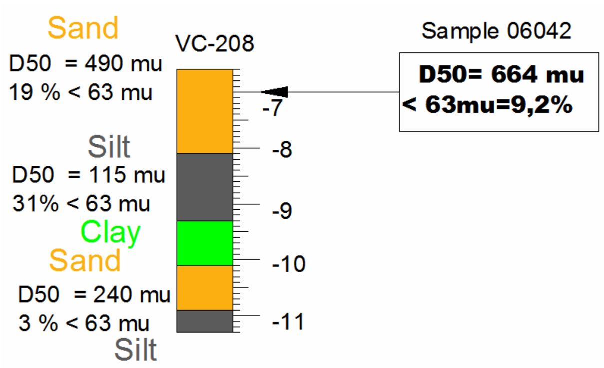
	%-fines	D_{50}
NTVC-01	3,6	373
Sample 29035	16	235



The samples are taken close together and give significantly different values. Below 9,5 m NSD the vibrocore gives a clay layer. It can be that the amount of fines increases with the depth. With this increase of fines, the D_{50} will decrease.

VC-208 versus Sample 06042
Distance between samples: 111 meter
Depth: 7 m-NSD

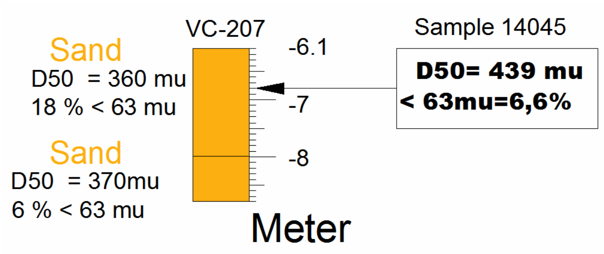
	%-fines	D_{50}
VC-208	19	490
Sample 06042	9,2	664



The samples show a totally different picture of the soil material at this depth. This only confirms the heterogenic composure of the seabed.

VC-207 versus Sample 14045
Distance between samples: 72 meter
Depth: 6,8 m-NSD

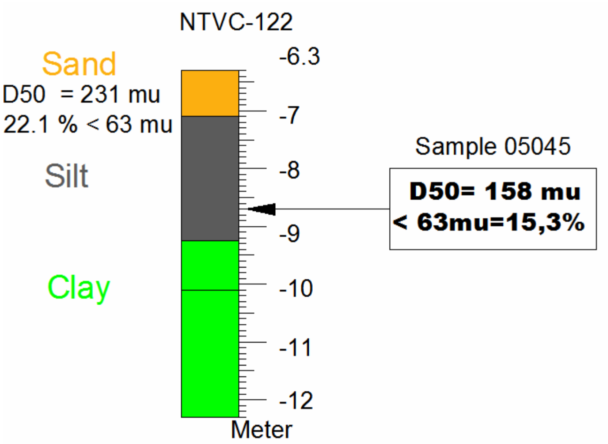
	%-fines	D_{50}
VC-207	18	360
Sample 14045	6,6	439



All samples that are taken around VC-207 in a radius of 200 meters give a D_{50} around 500 mu and a percentage of fines around 7. This doesn't give sense to the fine material that is present in the vibrocore. The lower sand layer of the vibrocore is more reprehensive for the samples from the inlet.

NTVC-122 versus Sample 05045
Distance between samples: 158 meter
Depth: 8,7 m-NSD

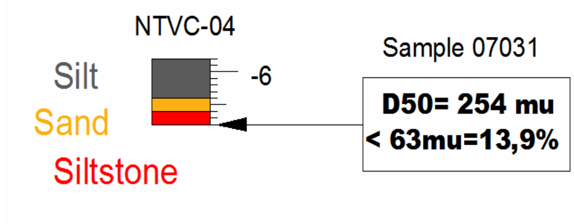
	%-fines	D_{50}
NTVC-122	SILT	SILT
Sample 05045	15,3	158



The vibrocore and sample 05045 both show fine material. During the vibrocore campaign the fine material was interpreted as silt and not tested in the laboratory. Because of this fact the samples seem to be similar.

NTVC-04 versus Sample 07031
Distance between samples: 95 meter
Depth: 6,77 m-NSD

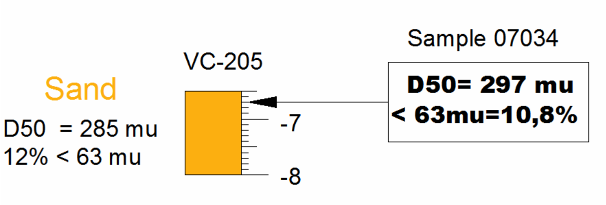
	%-fines	D_{50}
NTVC-04	SILTSTONE	SILTSTONE
Sample 07031	13,9	254



The vibrocore gives siltstone while the suction head is in a deeper level than assumed to be possible. The siltstone can be locally or the suction head opened the layer of siltstone. The vibrocore gives no information about the material underneath the siltstone layer, this way it can not be compared to the material of sample 07031.

VC-205 versus Sample 07034
Distance between samples: 40 meter
Depth: 6,7 m-NSD

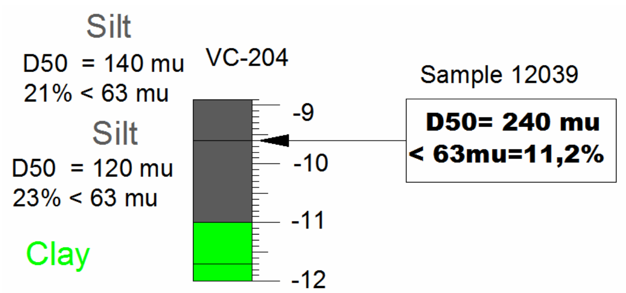
	%-fines	D_{50}
VC-205	12	285
Sample 07034	10,8	297



The samples give similar results. But sample 07034 exists out of slightly coarser material.

VC-204 versus Sample 12039
Distance between samples: 126 meter
Depth: 9,6 m-NSD

	%-fines	D_{50}
VC-204	22	130
Sample 12039	11,2	240



The samples show totally different results. The vibrocore shows much finer material. A sample 11035 that is taken on a distance of 177 meter gives more similarity to the vibrocore with a D_{50} of 157 and a percentage of fines of 27,8.