Environmental dredging operations in the Netherlands: a functional approach
Chemiehaven Rotterdam and the Haringvliet Estuary

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Abstract:

What can be done when there is a national environmental dredging programme but insufficient capacity for the disposal of all the contaminated dredged material or when the available finances are insufficient to pay for a total clean-up operation? This paper will show how a functional approach can counter some of the environmental risks.

The Chemiehaven (Chemical Harbour) in Rotterdam is a 22-hectare harbour basin situated in the Botlek area. In the sixties, owing to industrial activities surrounding the harbour, the sediments in the harbour basin became contaminated. In 2003, in cooperation with the major users of the Chemiehaven, Rijkswaterstaat, tackled the environmental risks by carrying out a 350 000 situ-m^3 environmental bulk dredging operation using the dredging equipment that is normally used for maintenance dredging in the port. In combination with a dedicated monitoring programme, this project was completed against low costs.

The Haringvliet Estuary and adjacent waters are part of the delta in the south west of Holland. In this area, sediment originating from the rivers Rhine and Meuse became contaminated during the industrial revolution. The estuary contains a huge amount of contaminated sediment (some 100 Mm^3) and it was realized that creating a disposal site for this amount of sediment would be expensive and would certainly meet social and environmental opposition. However, environmental studies of the area indicated that some of the risks could be countered by taking a functional approach, i.e. by placing a layer of clean dredged material on top of the contaminated sediment. In 2003, an experimental dredging operation was carried out in the Haringvliet Estuary; Rijkswaterstaat succeeded in capping the contaminated sediment in a 16 hectare area with a 0.5 m layer of clean material.

The results of both operations were satisfying and it emerged that a complete clean-up operation would not be necessary.

Keywords: Environmental dredging, functional approach, capping, Chemiehaven, Haringvliet

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INTRODUCTION

Situated where important European rivers like the Rhine and Meuse flow into the North Sea, the Netherlands lies in the delta of these rivers. While struggling against the attacks of the waves of the North Sea, 'the low countries', at the same time enjoy using the water of the many rivers, canals, lakes and estuaries. Almost 30% of the area within the borders of the Netherlands consists of surface waters. In addition to water used for transport and recreation and for domestic and industrial purposes, the surface waters form a rich and unique ecosystem.

This is what the large areas of surface water in Holland should do. However, between 1950 and 1980 as a result of industrialisation the aquatic sediment of many harbours, lakes and rivers was contaminated. Industrial activities around rivers, channels and harbour basins in the Netherlands, Belgium, Switzerland, France and Germany caused this deterioration in the quality of the waters and the sediments. These countries are situated in the catchment areas of European rivers that have their delta in the Netherlands, with the Rhine as major contributor.

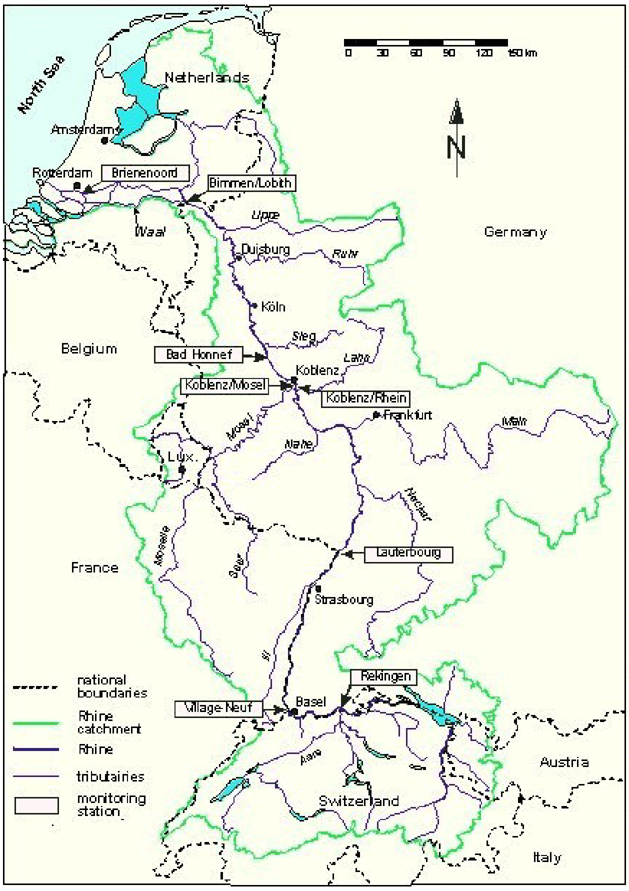

Figure 1: Rhine catchment area

Now, after eliminating the most direct sources of contaminants in Dutch surface waters as well as in the catchment area of the river Rhine, the Dutch government has introduced a 10-year programme to clean up these waters. There are several reasons why it is necessary to deal with contaminated sediments including:

- capital dredging or maintenance dredging in fairways and harbours,
- maintaining the capacity to transport water in order to guarantee water supplies for domestic and agricultural and industrial uses and to ensure that sufficient of the surplus water can be kept in temporary storage basins before ultimate discharge into the North Sea,
- and finally, there are the environmental dredging operations, often performed in combination with maintenance dredging.

As a result of this 10-year programme, many contaminated sediments have already been dredged and relocated.

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CONTAMINATED SEDIMENTS IN RELATION TO RISKS TO THE ENVIRONMENT

Awareness of the fact that during recent years or decades contaminated sediments have been accumulating in a river, channel, harbour basin or estuary leads to the question of what action, if any, should be taken to remedy the situation. Of course dredging is necessary when the nautical depth is to be maintained. But if it is necessary to initiate a dredging operation to remove the contaminated sediment from the environment, a combined maintenance and environmental dredging operation, or even a clean-up operation designed specifically to eliminate any environmental risk may be required.

First, it is necessary to investigate the risks that the contaminated sediment encompasses for its environment. Three types of environmental risk can be distinguished:

- the risk of contaminants being spread into surface waters,
- the risk of contaminants being spread into the groundwater,
- the risk of contaminants being directly taken up into the ecosystem and dispersed to a wider area.

The result of the investigation may be that in a specific situation one or two of these risks are encountered, while in some cases all three exist. In this situation, the first reaction will be to attempt to devise a clean-up operation in order to remove the contaminated sediment (Case 1). However, there may be insufficient financial resources to pay for an expensive total clean-up operation (Case 2), or there may be a volume of contaminated sediment that far exceeds the storage capacity of the available disposal sites (Case 3). The latter situation often arises in the Netherlands.

CASE NO. 1; ENVIRONMENTAL DREDGING OPERATIONS, IN GENERAL

(Effects and environmental acceptability)

As argued in the previous section, when a problem with contaminated sediments is identified in a maintenance area, one or more environmental risks may be detected and preferably, some action should be taken. Ideally, an environmental dredging operation that is designed to remove the contaminated sediment with a minimal effect on the environment would solve the problem. Focusing on the two aspects of removing all the contaminated sediment (without leaving any residue) and doing this with the minimum effect on the environment, leads to a very cost-intensive environmental dredging operation.

When planning an environmental dredging operation it is first necessary to select a suitable dredger for the specific location. Then it is necessary to concentrate on the question of the need to take measures to avoid harmful effects to the environment such as spillage and turbidity.
There will always be some spill during the dredging activity. This is sediment that is disturbed by the draghead, cutterheads, bucket or grab/clamshell, but is not removed from the location. It is impossible to dredge without any spill. Turbidity is caused by sediment brought into suspension during dredging. This suspended sediment can be transported by the river or by tidal flow and settles in or close to the dredging area. It is impossible to dredge without causing any turbidity, but the suspended sediments soon settle. Even when there is no dredging activity turbidity is caused by shipping movements (in fairways and harbours) or by tidal flow, river flow or waves.

In an environmental dredging operation, the public demands that there should be neither spill nor turbidity, while at the same time requiring a high degree of accuracy. Removing more sediment than necessary will result in high costs at the disposal site. Removing less sediment than necessary will result in a layer of contaminated sediment remaining as a residue after dredging.
To meet these demands, measures can be taken to avoid spill and turbidity. These measures include:
(*a*) selecting appropriate dredging equipment that is specially designed for environmental dredging,
(*b*) controlling the rate of dredging process (neither to fast nor too slow)
(*c*) automation of the dredging process to get optimum control of (*a*+*b*).

In order to meet the demand to dredge to a high degree of accuracy in clean-up dredging operations, it is necessary to maintain good positioning and to dredge at the right depth. This implies using a detailed, GPS-based monitoring system, in combination with a Digital Terrain Model (DTM). Although it is not possible to remove the entire contaminated layer, only a detailed DTM provides a tool that can focus on this specific layer. The DTM presents the layer as an assembly of x, y and z coordinates, covering the entire dredging area. Here the challenge is to attain a good approximation of the DTM. Focusing on measures to achieve high accuracy and on

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the prevention of adverse effects (spill and turbidity) brings extra costs and will result in low dredging production.

Measures to avoid adverse effects
Adverse effects can be avoided by dredging accurately, at a fitting speed and in the correct position. A good monitoring system is not only very helpful, but is even necessary. A detailed and regular survey of the whole area, in combination with a DTM, will ensure that dredging takes place in the required position and in the correct sediment layer. Finally, measures must be taken that will minimize spill and turbidity, are adapted to the chosen dredging technique, and are appropriate to mitigate harmful effects on the environment. To this end an automated dredger can be helpful. Overall, these measures are expensive and will still not succeed in removing 100% of the sediment layer in question.

When planning and initiating a dredging operation, especially an environmental dredging operation, it must be understood that there is a direct relation between the percentage of a layer of contaminated sediment to be removed and the total costs. Total costs include the costs of surveying, dredging and relocation of the dredged material. The costs must be weighed against profit to the environment.

The costs of dredging in relation to profit for the environment
Planning an environmental dredging operation involves the removal of a layer of contaminated sediment. Usually the higher the percentage of this layer that is removed the higher the cost of the operation (Fig. 1).

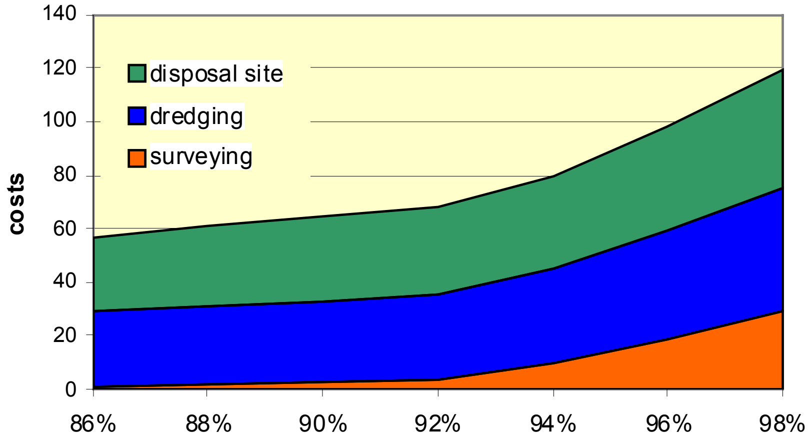

Figure1. Removal percentage and costs.

The higher the intended percentage to be removed, the more detailed and expensive the DTM, surveying or monitoring system. For instance, putting together a DTM for the relatively flat bed of a lake will require a grid of 50x50 m, one sample in each grid cell and two or more laboratory analyses per sample to determine the contaminants. With this, a statistical program has to be run to assess the accuracy of measurements and realisation. A detailed DTM gives a specific dredging depth for each point within the dredging area. Dredging accurately according this detailed DTM causes a loss of production in comparison to less accurate maintenance or capital dredging operations. At the same time, owing to some degree of inaccuracy of the DTM and the dredging techniques used, some of the uncontaminated sediment from the layer below will be dredged as well as a high percentage of the contaminate sediment. The higher the intended removal percentage, the higher the costs resulting from the loss of production and the dredging of extra sediment from a lower layer. The extra sediment that has been dredged to ensure that all the contaminated material has been removed has to be relocated with the contaminated material in a disposal site. In the Netherlands, storage space is scarce and, as a result, the cost of relocating dredged material is very high.

Environmental sound alternatives
The facts relating to environmental dredging give rise to questions such as: How much money are we willing to spend? Do we want to invest in accurate dredging and measurements and in appropriate measures, when it will be impossible to remove all the contaminated sediment and the dredging activity itself will not be completely harmless to the environment?

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To prove that environmental problems can be solved in a different way, by taking a more functional approach, two environmental dredging operations that were carried out in the Netherlands in 2004 are considered. The first was a clean-up operation in the Chemiehaven in Rotterdam and the second one an environmental dredging operation in the Haringvliet Estuary in the southern Delta area.

ENVIRONMENTAL DREDGING OPERATIONS, THE FUNCTIONAL APPROACH IN GENERAL

(An introduction to Cases 2 and 3.)

When choosing the most suitable dredging technique for a job an ordered approach must be taken.

1. Assess the environmental risks
   - Is there a risk of contaminants (in solution or bonded onto the sediment) being dispersed to the surrounding area via the surface water?
   - Is there a risk of contaminants being spread into the groundwater?
   - Is there a risk of contaminants being directly harmful to the ecosystem by entering the food chain?

   In a specific situation one, two or all of these risks may be encountered.

2. Take into account the dredging location:
   - Its function: must the water be deep or shallow at the location; is the location an isolated dredging area or an extensive area; is the area in use as a harbour; is there a fairway?
   - The local obstructions or restrictions, such as a harbour entrance, a dock, jetties or quay walls, a strong flow or high waves.

3. It is equally important to have site-specific data on:
   - The expected kind of sediment or subsoil below the contaminate layer. Will it be necessary to dredge silt, sand, clay or peat?
   - What other kinds of materials can be expected, for instance gravel, but also pipelines, drains and cables or debris and rubbish, possibly including anchors or fishing nets, or even cars, wrecks or bombs.

4. Only at this stage can the specific environmental values of the location be taken into account, including:
   - the restriction that will be imposed by the environmental rules on spill and turbidity. For example, bearing in mind that the rules for a nature reserve differ from those for to an industrial area,
   - the measures required (according to these rules) and any additional measures that must be taken;
   - whether the measures may determine the costs or a fixed budget may determine the extent of the measures that can be taken.

In our opinion only by following this fixed order it possible to select the best (most appropriate) dredging technique for the location.

CASE NO. 2: CHEMIEHAVEN ROTTERDAM

Location in general

The sediments in the Chemiehaven Rotterdam (Fig. 2) became contaminated owing to industrial activities around this harbour basin during the sixties and the seventies of the last century. The contaminants are: dioxins, PCBs, oil and heavy metals (cadmium and mercury). Since the contaminating activities ceased, the older contaminated sediment layer of 1 m to 4 m has been more or less naturally capped by a 1 m layer of fresh, cleaner sediment. Maintenance dredging is necessary only occasionally and is carried out by removing material from the cleaner top-layer of sediments.

The water surface of the harbour basin has an area of 220 000 m^2.

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Figure 2: Chemiehaven Rotterdam.

1. The environmental risks
After environmental investigation and fieldwork, it was concluded that though the sediment was heavily contaminated, the only risk to the environment was the risk of contaminated sediments being spread to the surrounding area with fresh and clean sediments via the surface water. There was no evident risk of contaminants being spread into the groundwater or being directly harmful to the ecosystem.
The spreading of contaminated sediments into the surrounding area could be initiated by the propellers of manoeuvring ships. These propellers cause a high level of turbidity by re-suspending sediment, while the tidal current flowing out of the harbour basin could carry away the contaminated soil particles.
For many years it had been impossible to dredge and relocate the dredged material. In Rotterdam the Parrots Beak confined disposal site for seriously contaminated sediment was too small for the large quantity of contaminated Chemiehaven sediment. No alternative was available. Only in 2000 did the Slufter, the large 150 Mm^3 confined disposal site for contaminated marine sediments, became an option for relocating the heavily contaminated sediments from the Chemiehaven.

2. Location to be dredged
- The harbour basin is 1.200 m long and 250 m wide, an area totalling 220 000 m^2. The harbour is 10 m to 12 m deep. The total amount of contaminated sediment in the harbour basin was 350 000 m^3.
- Industrial activity continues on sites around the harbour basin. Raw materials and industrial products are transshipped at several jetties all around the basin. These jetties must always remain accessible and the navigational function of the harbour basin had to be maintained.

3. Location specific data
- Dredging on the slopes around the harbour basin would not be without danger; there was some risk that these slopes might not be stable, which could affect the surrounding area on which railways, chemical tanks and pipelines are situated.
- After the environmental investigation and fieldwork (cores and samples, deep soundings and backscatter monitoring), maps (x,y,z-coordinates) of different sediment layers were, made showing the less contaminated top layer and an underlying heavily contaminated layer.
- Historical investigation revealed the previous maximum depth of the harbour (also in x,y,z-coordinates). The plan was that the environmental dredging should restore the depth to the previous maximum.
- Historical data, together with the results of on-site investigation (deep soundings), indicated the maximum permissible dredging depth for slopes. This is the level to which dredging can be carried out without destabilizing the slope and jetty structures.
- It was to be expected that some harbour litter (ropes, chains, cables, plastics, etc.) would be found in the sediment around jetties and moorings.
- The natural geological structure of the harbour comprises a mixture of layers of sand, clay and peat.

4. Specific environmental values of the location
- The location has both harbour and industrial functions and was not considered to have specific ecological goals or functions.
- After a clean-up operation, some spill or pollution caused by the chemical and nautical activities in the harbour basin would remain. Although some new contamination of sediments is possible, this is not expected to exceed harmful levels. In this situation a total clean-up environmental dredging operation was not deemed very useful.
- Although adjacent areas also have no specific ecological values, their contamination level is lower and should not be increased.

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Remedy
- The objective was to remove the specific risks that had been identified.
- A simple environmental dredging operation was the best option, and as Rotterdam owns a suitable confined disposal site 'the Slufter', a relocation site was available.

Planning the environmental dredging operation for the Chemiehaven
With the Slufter depot to hand, there were no relocation problems to be solved. In fact, two questions had to be answered before the environmental dredging operation could be carried out, these being:

a. Who would initiate this dredging operation?
b. Could a budget high enough to pay for the environmental dredging operation, be generated?

Re (a): There were three stakeholders concerned in the environmental dredging operation in the Chemiehaven. Firstly, the Ministry of Transport, Public Works and Water Management, which is the authority responsible for the quality of the river, canal and harbour beds in the Netherlands. Secondly came Rotterdam Municipal Port Management, which is responsible for harbour depth and nautical functions in the Chemiehaven as a part of the Port of Rotterdam. The third stakeholder was the AKZO Nobel company, which today is the most important user of the Chemiehaven harbour basin and which, when the decision was taken to carry out the environmental dredging operation in the Chemiehaven, offered to bear a share of the costs. In fact, the three parties agreed to cooperate equally in an environmental dredging operation that would eliminate the environmental risks. This common action had to be taken on a low budget because each partner owing to economy measures and economic setbacks had a low budget.
Re (b): The 'polluter pays' principle could not be applied to the project, since the pollution (originating from spill and by waste water being brought into the surface water) had been caused by more then one user of the harbour basin, as well as by the industries situated around it and, moreover, dated from a period before 1975. This made it legally impossible to recoup the costs of dredging from the polluters. Together the Ministry of Transport, Public Works and Water Management, Rotterdam Municipal Port Management and AKZO Nobel decided to initiate a low-budget environmental dredging operation and each was willing to pay a one-third of the costs. They decided to implement a bulk dredging operation, which meant:

- removing the major part of all the contaminated sediment,
- dredging to the maximum previous harbour depth,
- dredging only those sediments that could be easily reached on the slopes and in the central harbour area, without destabilizing the slope construction or endangering structures in and around the harbour basin,
- using trailing suction hopper dredgers, in combination with a bed leveller, and a grab dredger, and employing a crane with a rake-extension to collect the harbour litter before and during the dredging activities,
- using a monitoring system to ensure that suspended sediment, did not leave the harbour basin in great quantities (and producing proof of this to environmental commissions),
- proving the feasibility of this plan by making a test with a trailing suction hopper dredger, in combination with an OBS monitoring system (Fig. 3).

After the dredging operation, the harbour was quite deep. Because of this, turbidity from ships' propellers is reduced. Besides this, the deepened harbour basin will stimulate new sedimentation, probably more than the average yearly 14 000 m^3 of sediment. This new sediment layer will cover the contaminated sediment that remained in the harbour basin after the dredging operation.

Figure 3: Trailing suction hopper dredger at work in Chemiehaven.

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Execution of the dredging operation
After successful tests had proved that the work could be done as planned and with predictable results, the environmental bulk dredging operation was carried out. The results are presented in Table 1.
For details of this environmental bulk dredging operation in the Chemiehaven Rotterdam, reference may be made to the paper presented by mr. A.A. van Hassent of the Rotterdam Municipal Port Management.

Activities	*quantity*	*costs*
Dredging: Trailing suction hopper dredger + grab dredger + bed leveller Removing harbour litter	in–situ 302 300 m^3 340 m^3	€ 1 219 984
Monitoring		€ 156 139
Disposal site, costs of storage	ex–situ 416 736 m^3	€ 2 833 805
Total	excl. disposal: € 4.55/m^3 incl. disposal: € 13.93/m^3	€ 4 209 928

Table 1: Results of environmental bulk dredging operation Chemiehaven.

Presenting these results in a way comparable to figure 1 leads to the diagram of figure 4.

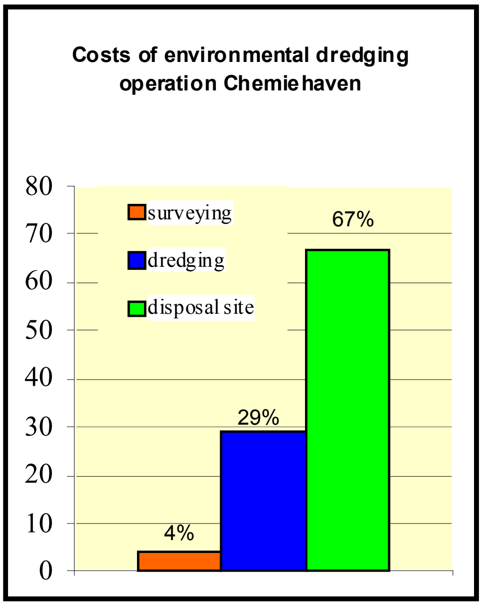

Figure 4: Results of the environmental bulk dredging operation Chemiehaven – the costs in percentages.

It is now up to natural processes to cover up the remaining contaminated sediments with fresh sediments that are either clean or at least far less contaminated. The new sediments (natural capping) will be monitored in the years to come.

CASE NO. 3: HARINGVLIET ESTUARY (southern Delta area)

Location in general.
After the completion of the Haringvliet dam as a part of the Delta-works (ca. 1970), during the seventies and early eighties of the last century, contaminated sediments brought into the system by the rivers Rhine and Meuse accumulated in parts of the Haringvliet Estuary. Now, since the elimination of most of the sources of

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contaminants in the Dutch surface waters as well as in the catchment area of the river Rhine, the fresh sediment is either clean or far less contaminated. The Ministry of Transport and Public Works studied the Haringvliet Estuary to determine how to handle the heavily contaminated sediments from the past.

Figure 5: Haringvliet.

1. The environmental risks

Investigation of the environmental risks indicated that in the Haringvliet Estuary the following must be considered:

- the risk of contaminants being spread in solution via the surface waters, or via dispersal caused by erosion during periods of storm or high river water outflow,
- the risk of contaminants being directly harmful to the ecosystem and spreading through the food chain,
- or both these risks occurring at the same time.

There seemed to be no risk of contaminants being dispersed into the groundwater.

These risks are caused by an volume of ca. 40 Mm^3 of contaminated sediment, that formed a layer varying in thickness from two or three decimetres up to a metre or more. Although a relocation site has been designed and will be built in the nearby Hollandsch Diep area, this confined disposal site will have a capacity of only a few Mm^3 of contaminated sediments.

2. Location to be dredged

The Haringvliet Estuary is a vast area (length: 28 km, water surface: 70 Mm^2), which is quite distinctive in appearances (Fig. 5). It consists of former trenches and pits, and underwater slopes and banks. The depth of the water varies from less then 1 m close to the banks, to a few metres on slopes and 10-30 m in trenches and pits. The Haringvliet is too large an area to be considered as a single dredging location. The risks will be handled by studying comparable parts of the Haringvliet and trying to design fitting environmental measures for these specific parts.

During the environmental dredging activities, the functions as described in Section 4 must be maintained.

3. Location specific data

The Haringvliet Estuary is a wide area with banks that are partly protected by breakwaters, underwater slopes a few metres deep and former trenches and pits that are 10 m to 30 m deep. On the banks, between the breakwaters and dry land, there are shallow waters up to 1 m deep. There is a slight tidal movement of some decimetres. The natural geological structure in the Haringvliet is made up of layers of sand and clay, which are the sediments of past eras. The area is still filling up, but now with fresh sediment that is clean or at least far less contaminated than previous sediments. This process of sedimentation is developing slowly at a rate up to of one or two centimetres a year.

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4. Specific environmental values of the location
- The functions of the Haringvliet are to provide an outlet for water flowing to the North Sea, a fresh water reservoir for agricultural use and a commercial fishing area. Besides this, the Haringvliet has nautical and recreational functions and lastly, it is a unique ecosystem with many species of plants and animals.
- These functions should be maintained in their entirety during any environmental dredging operations.

Remedy
The objective is to remove the specific risks that have been identified, doing this by means of an environmental dredging operation or capping or by a combination of both these measures.

Planning the environmental dredging operations for the Haringvliet Estuary
The Ministry of Transport, Public Work and Water Management conducted environmental investigations for the entire Haringvliet Estuary and published their conclusions in a document on the environmental operations for the area. In this document the following environmental measures for parts of the area are described:

- for banks and slopes where a few decimetres of extra water depth will not cause a problem: environmental dredging by removing all the contaminated sediment and relocating the dredged material in the Hollandsch Diep disposal site, (only a few Mm^3 from the Haringvliet can be relocated there),
- for banks and slopes, where extra water depth will harm the ecosystem: environmental dredging by removing some or all the contaminated sediment (which is to be relocated in the Hollandsch Diep disposal site) and capping or refilling the dredged area with sand or clay,
- for former trenches and pits: capping the contaminated sediments with a 0.3 m to 0.5 m layer of clay or sand. In a way this can be seen as assisting the natural processes that are capping the sediments in the pits and trenches with fresh, uncontaminated sediment, although this is proceeding too slowly to effectively diminish the environmental risks within the desired time.

When environmental dredging operations in the Haringvliet area are being planned in the years to come these options will be used as a starting point.

The capping option tested for the Haringvliet circumstances
In 2002, the capping option, one of the environmental measures for the Haringvliet, was tested. The capping option is essential for most parts of the Haringvliet, because by this method the environmental risks can be dealt with while:

- no sediment is being removed and so relocation is not necessary,
- it can be very cost effective when quantities of clay or sand that are the surplus from large-scale infrastructure operation are available free.

A trench in the eastern part of the Haringvliet was selected for the test (Fig. 6). The water depth there was 6m to 8 m. During 5 months 118.000 m^3 of clay, the surplus from a nearby harbour extension, was used to cap 160 000 m^2 of consolidated, contaminated sediment. Two different ways of capping were tested: positioning the clay on the sediment layer by using a grab dredger and using a specialized rock dumping vessel that is usually operates in constructing bottom protections in front of quay walls.

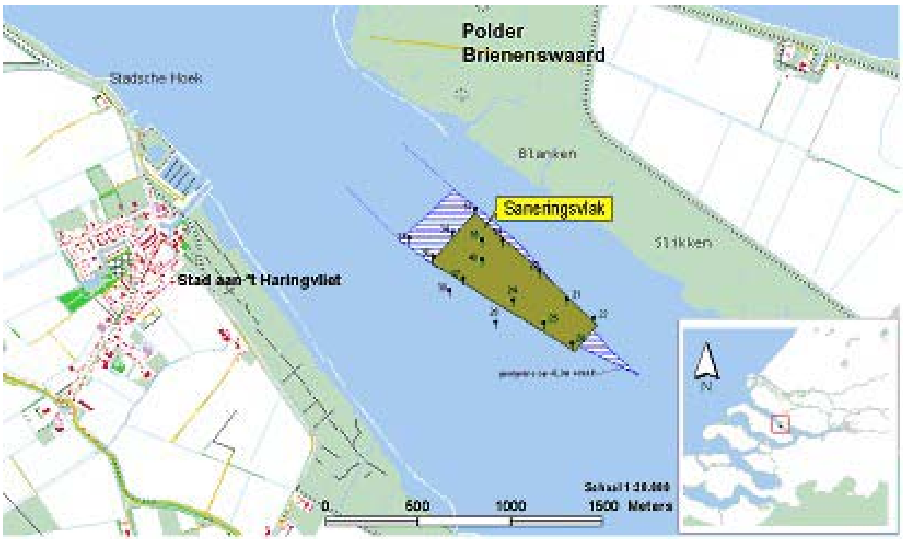

Figure 6: Haringvliet, location to be capped.

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An extensive monitoring system accompanied the trial.
The thickness of the clay capping layer was monitored by taking soundings as well as by taking cores. The results of the various capping technique are presented below.
From time to time, turbidity monitoring was carried out by a survey vessel that took samples. From the characteristics of the material, it could be shown that fines from the plume had their origin in the covering clay. Only a very small amount of contaminated sediment was found in suspension.
This was confirmed by the results of sediment samplers positioned around the capping location. Although sedimentation was more than average, hardly any contaminated sediment was found; the sediment seemed to originate from the clay that had been used for the capping. The macro-fauna was monitored before and immediately after the capping and will be monitored again in 2005. The results will be compared with a reference area where no capping has yet been carried out. From this we hope to learn about the effects of a capped area on the macro-fauna compared to the non-capped reference-area.

Capping with the grab dredger 'VOW 702'
One cannot expect to obtain a smooth surface of clay on top of the contaminated sediment when capping with a grab dredger. So to be sure that a minimum layer thickness of 0.3 to 0.5 m was achieved, the process of capping with the grab dredger was designed to produce an average layer thickness between 0.7 and 1.2 m. In practice, the grab dredger created an average layer-thickness of 0.72 m. Soundings proved that there was never a conflict with the preset minimum.
On site the grab dredger positioned itself on spuds.

Figure 7: Capping with the grab dredger.

The grab dredger used for capping was equipped with a chessboard monitoring system, each square visualizing the area to be capped by a single fully loaded grab. Thus, the grab dredger operator is able to cap the area by 'simply' filling up each square on the chessboard monitor; as this is done the square on the monitor changes colour. In the trial, the grab dredger performed the capping in three different ways: with the grab opening above the surface of the water, opening at the surface level and opening underwater. The monitoring focused on whether there would be any difference in the turbidity caused by the capping methods or in the quality of the capping layer. Comparison of the results for those parameters showed that there was no significant difference between these three methods. The results in quantities, production and costs are given in Table 2.

Environmental capping Haringvliet - Test 2002							
dredger	quantity		productions		costs		
	m^3	m^1	m^3/day	m^2/day	Euro/ m^3 clay	Euro / m^2 capped area	Euro / m^3 contaminated sediment
grab dredger ' VOW 703'	13 395	0.72	1 460	1 520	2.32	2.22	5.54
rock dumping vessel 'Pados'	82 671	0.59	1 490	2 130	2.53	1.77	4.44
Total	96 066	-					

Table 2: Results of the environmental capping

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Capping with the specialized rock dumping vessel 'Pados'
The 'Pados' can best be described as pontoon with a flat mid-section that is without a fixed bottom and which is about 1 m free of the water surface. This midsection is divided into 8 x 4 = 32 boxes of each 4 m^2. In this section, a bottom plate can be shifted so that half of the 32 boxes discharge their load. At the moment when the bottom plate is moved, 16 x 4 = 64 m^2 clay will fall straight through the water column towards the sediment to be capped (Fig. 8). Because of the large surface being capped in one movement of the bottom plate, it was possible to create a far smoother layer surface with the 'Pados' than with the grab dredger. The desired layer-thickness is attained by placing a specific amount of clay on top of each bottom plate. It will be clear that the 'Pados' can produce a layer-thickness close to the preset minimum of 0.3 to 0.5 m. In the test, a capping layer with an average thickness of 0.59 m was achieved. When the economics of the use of capping material are being assessed, this is indicates a good performance. Soundings proved that there was no conflict with the preset minimum requirement.
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Figure 8: Midsection of the specialized rock dumping vessel

On site, the 'Pados' positioned itself on spuds and was loaded by a grab dredger (Fig. 9). Besides spuds, the 'Pados' was well equipped with winches and anchors so that loading, capping and positioning formed a continuous process, interrupted only by the changing of the clay transporting barges or relocation of the anchors. It was mainly due to this continuous process that the production of the 'Pados' was better than that of the grab dredger (Table 2). Like the grab dredger, the 'Pados' was equipped with a chessboard monitoring system, each square visualizing the area that could be capped by the16 boxes that formed half the load of the midsection of the 'Pados'. Again, the driver could cap the area by simply filling up each square on the monitor and was done the square on the monitor changed colour.

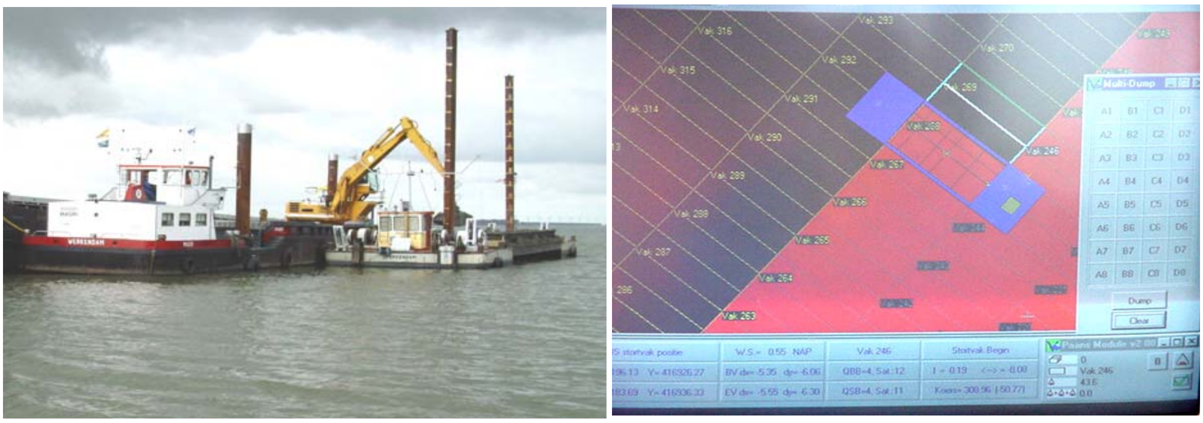

Figure 9: Capping with the specialized rock dumping vessel

Conclusions on capping techniques tested at the Haringvliet
Both capping techniques, (with a grab dredger and with the specialized rock-dumping vessel), gave good results. The capping provided a 100% cover. The turbidity caused by the dredging activities did not seem to cause an environmental problem; the fines that were brought into suspension did not originate in the contaminated

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Haringvliet sediment. The use of the ‘Pados’ on location requires the use of extra floating equipment and is thus cost intensive. However, due to the good production and the smooth capping layer, the ‘Pados’ achieves a lower price per m^2 of capped area, while making more economical use of capping material. Capping has proved to be a good solution, permitting environmentally sound operations in the Haringvliet area. As soon as further free capping material becomes available, the next location in the Haringvliet will be selected for capping.

GENERAL CONCLUSION

It is not always necessary to organise a total environmental dredging clean-up operation when there are contaminated sediments in a river, channel or harbour basin. Sometimes a thorough analysis of the problem, followed by a functional approach, leads to a more effective solution. This permits the selection of techniques to suit the specific problems.

- First, take into account, the environmental risk(s) that are generated by the contaminated sediment at the location. Do these environmental risks demand a specific solution? For instance, is it really necessary to remove and relocate all the contaminated sediment or are other measures possible and perhaps more desirable?
- Secondly, take into account the specific dredging location, including its function and its functional restrictions, the data on the kind of sediment or soil and other materials expected at the site,
- When an environmental dredging operation seems to be necessary, bear in mind that environmental dredging will also inevitably result in some spill and turbidity. It is not feasible to focus on a 100% clean up of the location and even the clean-up operation itself always produces some undesired effects

The Chemiehaven of Rotterdam and Haringvliet cases showed that for these locations a total clean-up operation was unnecessary. Here the environmental risks could be dealt with by carrying out low-budget operations; the functional approach resulted in effective environmental dredging or capping operations that each proved successful.

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