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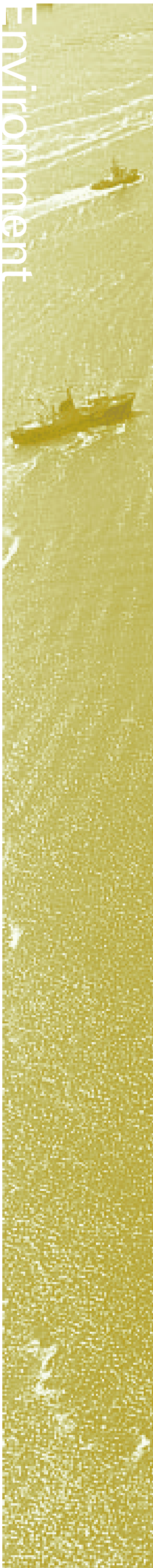
Chemical Monitoring of Maintenance Dredging Operations at Zeebrugge



Abstract

Under the auspices of the Waterways and Marine Affairs Administration of Flanders, Belgium, an intensive research project to evaluate the ecological impact of dredging and relocation operations in the Belgian Coastal Zone has been conducted over the last 5 years. The Port of Zeebrugge, which is the major harbour in this area, was chosen as the appropriate place for evaluation.

Two different dredging techniques were compared: the hopper dredger equipped with standard suction pipes and an environmental valve in the overflow funnel; and the hopper dredger, equipped with a specially designed re-circulation pipe.

Whilst during the MOBAG 2000 project all three major effects (physical, chemical and biological) caused by dredging operations were studied, this article primarily focuses on the chemical impact on the environment.

Introduction

In 1995 the Waterways and Marine Affairs Administration of Flanders, Belgium started an intensive research project in order to evaluate the ecological impact of dredging and relocation operations in the Belgian Coastal Zone. Since the major part of the dredging activities there consists of maintenance dredging with trailer suction hopper dredgers, most of the studies conducted for MOBAG 2000 are focused on that type of dredging.

Localisation

Zeebrugge is the major harbour in the Belgian Coastal Area, where annually about 5.1 million tonne dry material has to be evacuated to maintain the navigational depth up to 13.5 metre TAW (Figures 1 and 2). As do many harbours, the Port of Zeebrugge suffers from intense sedimentation in the form of fluid mud entering the harbour during high tide. In the Central Part of the Outer Harbour (CDNB) alone, the average daily sedimentation rate exceeds 12 400 tonnes dry material. The maintenance dredging of the harbour is done exclusively by means of trailing suction hopper dredgers which bring their loads to disposal areas respectively at 4 and 17 km off the coast (B&W Zb oost and S1).

Although during the MOBAG 2000 project all three major effects (physical, chemical and biological) caused by dredging operations have been studied, this article will primarily focus on the chemical impact on the environment.

Method

Studies have been carried out on the three main phases of dredging. They include:

- the characterisation of the in situ sediments;
- physico-chemical changes in the sediment during different phases of the dredging process on board the dredger; and
- studies at the disposal areas.

In Situ Sediments

Pollutants

The sediments of the Outer Port of Zeebrugge are strongly reduced fine sediments with a density between 1.02 and 1.24 kg/litre. The heavy metal content in the sediment is fairly low and for all metals beneath the critical value of the Belgian criteria for disposal at sea. The metal concentrations in the pore water are very variable and are the highest for As and Zn. The concentration of organic pollutants (PAHs) is low (1-1.5 mg/kg DM for the sum of 16 PAHs).

The variability of the mobility of arsenic and zinc was the subject of a study in April 2000.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Alain Pieters graduated as a geologist and a soil scientist. In 1989 he joined Jan De Nul as a surveyor in the hydrographical department. Since 1995 he worked as a geo-technician and recently he has joined the environmental department.


Marcel Van Parys

Marcel Van Parys has been involved since 1981 as an industrial engineer (civil engineering) in the overseas hydrographical department of Jan De Nul. For the last 5 years he has been responsible for the environmental monitoring department.


Guido Dumon

Guido Dumon holds degrees in chemical engineering and in environmental sanitation engineering. He is a senior engineer at the Ministry of the Flemish Community, where he heads the department of hydrometry and the environment.


Lode Speleers

Lode Speleers studied agricultural and environmental engineering at the State University of Ghent and was head of the environmental departments at several companies. Recently he became the director of ERC (Environmental Research Centre).

An extensive sampling campaign was organised in order to investigate the evolution of the mobility of arsenic and zinc as a function of the sediment density. For that purpose a newly designed multi-sampling device, capable of sampling sediments in a wide density range, was successfully used (Figure 3). A total of 70 sediment samples, spread over 10 locations in the CDNB, were collected.

The mobility of both heavy metals, chosen for their relative high pore-water concentrations measured during previous investigations, was evaluated by analysing different physico-chemical parameters, the evaluation of the distribution coefficients and the determination of the SEM/AVS ratio, which give an indication of the toxicity of the sediment for bentic organisms.

On the bulk sample acidity, redox potential, dry matter content, density, grain-size distribution, arsenic and zinc content were determined. On the pore waters the following parameters were determined: acidity, redox potential, arsenic content, and zinc content.

During the analysis of arsenic and zinc severe quality control was done, including the use of duplicate measurements, matrix spikes and recovery of certified material (CRM 320).

From the analysis it appears that most physico-chemical parameters of the loose sediment in the CDNB vary slightly, except in the top layer of the in situ sediments. This points to the fact that the thickness of the oxic-anoxic interface layer is very limited.

Evaluation of the distribution coefficients (Kd) of arsenic and zinc showed that both elements show a sharp decrease of mobility with increasing depth in the upper half metre of the sediment. Deeper in the sediment the mobility of arsenic increases again with depth. On the contrary, the mobility of zinc decreases further with depth.

The mobility of arsenic and zinc were significantly correlated to the density but not to the redox potential and the acidity of the sediment. The correlation between the arsenic concentration in the pore water and the acidity of the pore water was however significant.

In general the mobility of arsenic is much higher compared to zinc (average Kd resp. 0.6 and 18.2 l/g).

The results for the SEM to AVS ratios showed that no toxicity as a result of the bio-availability of heavy metals should be expected. As a matter of fact, these results were confirmed by ecotoxicity experiments which have been finalised recently at the laboratory of the University of Ghent in co-operation with EURAS (Figure 4).

Figure 1. Aerial view of the Port of Zeebrugge, looking east toward the hinterlauds.

The tests were conducted with organisms representing several trophic levels and produced no acute toxicity. An overview of the test organisms and methods are given in Table I.

Nutrients

The in situ sediments have about 3 gram Kjeldahl-Nitrogen/kg dry matter, 0.5 gram NH4-N/kg DM and 1 gram P/kg DM. Analysis on the sediments pore water revealed that the Kjeldahl nitrogen occurs predominantly under the form of ammonium-N (70 to 90%) compared to only 15% in the total analysis on the sediment. Apparently ammonium is more mobile and is more easily released to the pore water. The Kd of phosphorus is much higher than the Kd of total N and is therefore less liberated in the pore water.

From this study it can be concluded that:

- The in situ sediments have a fairly low pollution degree.
- There exist natural temporal and spatial variations in the mobility of arsenic and zinc which have to be taken into account when evaluating the ecological impact of dredging.

On Board The Dredger

The ecological impact of dredging activities was determined by means of evaluating the mobility of contaminants and nutrients during the dredging cycle of the hopper dredger *Cristoforo Colombo* (Figure 5).

Two different dredging techniques were compared:

- the hopper dredger equipped with standard suction pipes and an environmental valve in the overflow funnel; and
- the hopper dredger, equipped with a specially designed re-circulation pipe.

To obtain good insight into the different phases during dredging the following sampling campaign was set up: In situ samples were taken in the dredging area.

The samples taken whilst dredging with the hopper dredger can be subdivided in three groups:

- samples of the dredged material when leaving the hopper line and entering the hopper;
- samples of the overflow; and
- samples in the hopper well just before disposal.

Figure 2. Close-up helicopter view of the Port of Zeebrugge.

In order to evaluate the mobility of contaminants between different phases of the dredging cycle, the following parameters were determined on the samples:

- physico-chemical parameters (redox, pH, dry matter, density, carbonates, grain-size and organic matter);
- natural and heavy metals (Mn, Fe, Al, As, Hg, Cd, Pb, Zn, Cu and Ni); and
- organic contaminants (PAHs).

Pore water analysis focused on the 11 metals mentioned above. Also the following parameters were determined: redox, pH, conductivity, Kjeldahl and ammonium nitrogen, total phosphorus, chloride and sulphate.

In order to assess the mobility of contaminants, distribution coefficients were calculated and finally sequential extractions on 11 metals following the "BCR-3 step" procedure were performed.

Heavy metals

During dredging the concentration of As and Zn have a tendency to rise (with approximately 50 µg/litre) whilst dredging with the re-circulation head. With the environmental valve the evolution is less clear.

Ni, Cu, Cd and Hg show no significant variation during dredging except for Ni where a minor decrease can be noticed. Concentrations in the pore water are generally low (Ni, Cu) or very low (Cd and Hg).

Mn and Fe concentrations in the pore water are very high (respectively, 10 to 35 and 10 to 15 mg/litre). Although iron increases, the manganese content shows almost no variation during dredging.
The aluminium content is much lower (max. 400 µg/l) and increases slightly with the re-circulation pipe.

By calculating the distribution coefficients (Kd values), the heavy metals can be grouped by their tendency to become mobile. The mobility decreases as follows: As>Zn>Cu=Ni>Pb=Cr.

For the natural metals manganese is the most mobile element, followed by iron and aluminium. When assessing the mobility by comparing the Kd values from the in situ samples and the samples during

Table I. Overview of the bioassays used.

Species tested	Elutriate test		Sediment suspension test	
	Duration	End point	Duration	End point
Algae *Phaeodactylum tricornutum*	72 h	Growth	7 d	Growth
Crustaceans *Americamysis bahia*	96 h	Mortality	7 d	Mortality/growth/ reproduction
Tisbebattagliai	48 h	Mortality	7 d	Mortality
Fish *Dicentrarchus labrax*	96 h	Mortality	14 d	Mortality/growth

dredging (see Table II) one can conclude that the Kd value varies slightly and that this variation is different for every metal.

The sequential extractions on the in situ samples revealed that most metals were found in the third step (organic matter and sulphide bound) and in the residual fraction. Only nickel is partially mobile (first step is = 10%) and cadmium was found mainly in the third step, which could mean that it is mostly precipitated as a sulphide. Forty percent of the manganese is found in the most mobile fraction.

When comparing the two dredging techniques the conclusion is that the shift to more immobile fractions differs for every metal considered (Table III). It should, however, also be noted that all the observed shifts were very small.

Other parameters
During dredging the ammonium-N decreases in comparison to the in situ sediment, except for the samples just before disposal when dredging with the re-circulation head. The same evolution is more or less observed for Kjeldahl-N.

Figure 3. Detail of new multi-sampling device for sampling fluid mud.

Figure 4. Detail of new multi-sampling device for sampling fluid mud.

The pH of the sediment increases slightly during dredging. Although the redox potential of the sediment is not influenced by dredging, the pore water redox shows an evolution to less negative values at the end of the dredging cycle. The redox potential is however still strongly anaerobic (-150 mV).

Discussion

On the basis of the analytical results it is difficult to quantify the impact on the environment induced by dredging operations. Nevertheless, the results of the distribution coefficients and the sequential extractions give a good indication of the impact. Pore water analyses indicate that there is a not-negligible amount of metals which are liberated during dredging operations, especially As and Zn (approx. 50 µg/l). The free pore water in the overflow and in the hopper well can be liberated in the water column, respectively during dredging and disposal.

Nevertheless one should note that the liberated contaminants and nutrients will come into equilibrium by sorption and desorption processes (sorption of contaminants on sediment particles is a common feature). This fixation is seldom irreversible and because of changing chemical and physical conditions, the contaminants can be liberated again. The free pore water can be seen as a potential "reservoir" of contaminants and keeping the pollutant and nutrient concentrations in the pore water as low as possible during dredging and disposal is important.

On the other hand, contaminants bound to the sediment particles themselves can be liberated into the

Table II. Variation of the distribution coefficient (Kd) in function of the dredging techniques.

Parameters	Campaign 1 Re-circulation pipe		Campaign 2 Environmental valve	
	Kd overflow / Kd in situ (%)	Kd hopper well / Kd in situ (%)	Kd overflow / Kd in situ (%)	Kd hopper well / Kd in situ (%)
Al	+ 37	- 27	- 51	+241
Fe	- 93	- 92	- 60	- 65
Mn	- 16	- 12	- 28	- 31
As total	- 49	- 42	- 49	- 31
Cr	+ 69	+ 5	- 31	- 13
Cu	- 53.3	- 21.1	- 4	- 12
Ni	+ 11	+ 58	- 8	+ 12
Pb	- 73	- 43	- 55	+ 69
Zn	- 45	- 73	- 55	- 72
Sum	**- 212**	**- 247**	**- 341**	**98**
Average	**- 24**	**- 27**	**- 38**	**11**

Figure 5. The ecological impact of dredging activities was determined by means of evaluating the mobility of contaminants and nutrients during the dredging cycle of the hopper dredger, TSHD Cristoforo Colombo.

environment but the quantity and the velocity of these processes is difficult to estimate. Comparison between different studies conducted during the MOBAG 2000 project revealed that the mobility of heavy metals in the in situ sediments have a natural spatial and temporal variability. This has to be taken into account when evaluating the mobility caused by dredging operations.

Ecological Impact at the Disposal Site

To estimate the impact of disposal activities at the disposal areas, a study was conducted to evaluate the release of arsenic and zinc, the most mobile heavy metals. Therefore an extensive sampling campaign was organised in April 2000 during the disposal of dredged material from the harbour of Zeebrugge.
To avoid any contamination of the seawater samples during handling, the survey vessel *DN 62* was equipped with a laminar flow workstation (microsafe CLASS II SE) and special care was taken by using acid-rinsed filters, recipients, syringes and so on.

A total of 153 seawater samples were taken spread over 9 disposal cycles, and 34 samples were taken for the determination of the background values. Simultaneously the turbidity, the temperature and the salinity were measured by using an OBS-5 turbidity sensor. The seawater samples were filtered on board the vessel (Figure 6) and were sent to the lab for further analyses. On the samples the following parameters were determined:

- content of dissolved arsenic and zinc;
- redox potential;
- acidity; and
- conductivity.

During the analyses of arsenic and zinc, with an axial ICP-AES, the quality control was assured by the

Table III. Results sequential extractions: Evolution to more mobile fractions in function of the dredging technique.
+ shift to more immobile fractions; 0 no shift;
- shift to more mobile fractions

Parameters	Campaign 1 Re-circulation pipe Shift of fractions	Campaign 2 Environmental valve Shift of fractions
Al, Fe, Ni	+	-
Mn	-	-
As total, Cd	-	0
Cr	-	+
Cu	0	0
Hg, Zn, Pb	0	-

Figure 6. On board the survey vessel, filtration of the seawater samples in a laminar flow workstation were conducted prior to analysis in the laboratory.

execution of duplicate measurements and recovery matrix spikes.

Salinity and acidity did not seem to be affected by the disposal operations. However the redox potential of the seawater was clearly lower during disposal operations. This means that disposing of strongly reduced sediments has an important influence on the redox potential of the seawater, without seriously threatening the oxygen availability in the water column. The variation of the redox could not be statistically correlated to the turbidity.

The concentration of arsenic during disposal operations was higher compared to the background values. An average increase of 1.03 µg/litre dissolved arsenic above the background value (= 1.25 µg/litre) was observed.

The average dissolved zinc concentration of the first 4 disposal cycles was much lower than those of the 5 following cycles. The background concentrations were even higher compared to the samples collected during the disposal cycles. Stormy weather conditions occurring after the second day of the sampling campaign are a possible cause for the elevated dissolved zinc concentrations.

The turbidity measurements carried out simultaneously with the seawater sampling showed that sediment plumes on the disposal ground vanished after approximately 25 minutes. The highest concentrations that were measured occurred near the seabed and are as high as 6 to 8 gram/litre.

Ecotoxicity tests in which different organisms (see Table I) were continuously exposed to turbidity concentrations, comparable to those found at the disposal area, showed no effect compared to the control group.

Conclusions

General conclusions are difficult to draw. The mobility of contaminants in dredged material changes during dredging. This change is different for every examined contaminant. For some contaminants the mobility decreases; for others it increases. However it is important to note that the change in mobility is very low for all the considered contaminants and for both dredging techniques.

At the disposal area there are indications that arsenic is liberated to the surrounding seawater. However, the concentrations remain very low and in the laboratory no negative effects could be detected for the organisms tested.