Synthesis report on the effects of dredged material disposal on the marine environment (licensing period 2008-2009)

Brigitte Lauwaert¹, Karen Bekaert², Miguel Berteloot³, Annelies De Backer², Jozefien Derweduwen², Arvid Dujardin², Michael Fettweis¹, Hans Hillewaert², Stefan Hoffman², Kris Hostens², Stefaan Ides², Job Janssens², Chantal Martens⁴, Tinne Michielsen⁴, Koen Parmentier⁵, Gert Van Hoey², Toon Verwaest⁵

Report by BMM¹, ILVO², CD³, aMT⁴ and WL⁵ conform art. 10 of the R.D. of 12 March 2000 defining the procedure for licensing of disposal in the North Sea of certain substances and materials.

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Brigitte Lauwaert¹, Karen Bekaert², Miguel Berteloot³, Annelies De Backer², Jozefien Derweduwen³; Michael Fettweis¹, Hans Hillewaert², Stefan Hoffman², Kris Hostens², Chantal Martens⁴, Tinne Michielsen⁴, Koen Parmentier², Gert Van Hoey², Toon Verwaest⁵

¹ MUMM – Management Unit of the North Sea Mathematical Models and the Scheldt estuary, Gulledelle 100, 1200 Brussels.
² ILVO – Institute for Agricultural and Fisheries Research, Animal Sciences Unit – Fisheries, Section Monitoring, Ankerstraat 1, 8400 Ostend.
³ AMCS – Agency for Maritime and Coastal Services – Coastal Division, Vrijhavenstraat 3, 8400 Ostend.
⁴ AMT – Maritime Access Division, Tavernierkaai 3, 2000 Antwerp.
⁵ WL – Flanders Hydraulics Research, Berchemlei 115, 2140 Antwerp.

Also participated in this research:

ILVO: Mattias Bossaer, Lisa Devriese, Bart Goes, Lode Jacobs, Ellen Pecceu, Jan Wittoeck
MUMM: Els Monteyne, Dries Van den Eynede
CODA: Marc Guns, Paul Van Hoeyweghen
AMT: Natasha Blommaert, Vincent Vanianghelandt, Kirsten Beirinckx

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Contact:
b.lauwaert@mumm.ac.be; +32(0)2-7732120
kris.hostens@ilvo.vlaanderen.be; +32(0)59-569848
chantal.martens@mow.vlaanderen.be +32(0)3-2220883
oon.verwaest@mow.vlaanderen.be +32(0)3-2246187

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Summary

Introduction

To conserve the marine access channels to the Belgian coastal harbours and to maintain the depth of the Flemish coastal harbours, dredging is needed (Flemish competence) in order to guarantee safe maritime transport. This type of dredging is called maintenance dredging and it is the only type of dredging which is covered by this report. Most of the dredged material is being dumped at sea except when the quality is suitable for beach nourishment. The last use is called ‘beneficial use’ of dredged material.

The competence for dumping at sea of dredged material falls under the federal government. Therefore, the management of dredged material in Belgium is a mixed competence. A cooperation agreement between the Flemish Region and the federal government has been signed the 12th of June 1990 and was modified the 6th of September 2000.

The legal basis for the permitting procedure is the Royal Decree of 12th March 2000. According art. 10 of this Royal Decree, a synthesis report has to be established per permit period, accompanied by recommendations which support the development of an enforced environmental management.

Dredging and dumping activities

For the previous permit period April 2008 – December 2009, four permits were delivered to the Maritime Access Division and three permits were delivered to the Agency for Maritime and Coastal Services.

The total average permitted quantity for the Maritime Access Division was 21,045,000 TDS (tonnes dry substance) for four dumping sites and 1,170,000 TDS (tonnes dry substance) for the Agency for Maritime and Coastal Services for three dumping sites.

In the calendar year 2007, a total of 8,518,427 TDS has been dumped at sea by both permit holders and for the calendar year 2008 this total was 10,305,232 TDS. The dredging and dumping intensity maps for the calendar year 2008 are at annex 1.

For the period 2007-2008 approximately 110,000 m³ was used for beach nourishment (beneficial use).

Alternative dredging methods

In the period between 4/05/2009 and 2/06/2009 a pilot project was carried out in the port of Zeebrugge to examine the possibility to reduce the top silt layer in the port by means of alternative dredging techniques. The test took place in the Albert II dock. A stationary cutter dredger was used to dredge continuously during longer periods (a few days to a week) on the same location in the dock. A series of measurements was set up for the follow-up of the test, both for near and far field effects.

From this test can be concluded that local, intensive dredging causes a local and temporal lowering of the top mud layer. No systematic, long term effects could be distin-
guished from the available measurements. The density measurements show a local decrease in the density values, but no effects further on in the dock, as was originally expected.

The dredged material was dumped over the western quay wall. No significant influence on the local bathymetry could be found.

**Physical aspects related to dredging and dumping**

Large amounts of sediments are dredged in the Belgian nearshore area to maintain ships’ access to ports and harbours. The morphological and sedimentological effects resulting from these dredging and dumping works are numerous. The EU Marine Water Framework Directive provides a framework that embodies the principles of environmental protection, improvement and restoration on an integrated basis. In addition, the WFD specifies that there must be no temporal deterioration in chemical and biological status for many water bodies, and identifies (Annex VIII) ‘material in suspension’ as one of the main pollutants. When human activities occur in habitats characterised by cohesive seabed sediments or by high turbidities, resuspension of material or dredging and dumping can result in higher concentrations of suspended particulate matter (SPM), which can spread over large areas. Alterations of the cohesive sediment distribution are to be expected because infrastructure works, together with dredging and the disposal of sediments, often result in hydrodynamic conditions which are not in equilibrium with the present-day bathymetry. However, the manner in which the system reacts to large engineering works needs to be understood to ensure cost-effective operations at sea, to better gauge the human footprint, and to develop environmental policies aiming at a more sustainable management of the marine environment. Reference situations are rarely available in the marine environment and, therefore, true impacts are difficult to be assessed unambiguously. In addition, the natural variability of, e.g. sediment fluctuations is high in these dynamic settings; as such, the human footprint is difficult to identify.

In this chapter results of different studies are summarized that deal with sediment dynamics and human impact in the Belgian nearshore area.

**Erodibility of muddy sea bottom**

With financial support by BELSPO, in the framework of the QUEST4D project, experimental research to determine the erodibility of a muddy sea bottom was carried out by Flanders Hydraulics Research. At different locations in the Belgian coastal zone sea bottom samples were taken from the BELGICA platform using a boxcorer. Laboratory experiments on these samples were performed at the sediment lab of Flanders Hydraulics Research and also in a unique erosion flume developed and operational at the University of Stuttgart.

The test results show a very large variability of the erodibility of the muddy sediment, both in depth as in plan. This variation is caused by for example the variation in mud / sand ratio, the variation in the density and the variation in the organic matter content. Further empirical research is needed to complete mapping the erodibility of the sea bottom in the Belgian coastal zone. The results of the investigations have however already resulted in an improved insight. It appeared that the least consolidated, freshest mud on the seabed has a larger than previously anticipated critical shear stress for
erosion, but that the erosion rate parameter of this material is significantly larger than what was previously thought. Using numerical models can be tentatively explored what the consequences are for the questions about the overall mud dynamics in the Belgian coastal zone.

**Anthropogenic impact on cohesive sediment distribution and transport**

The construction of the port of Zeebrugge in the 20th century, including the dredging or deepening of navigation channels and the associated disposal of sediments, represents the most conspicuous anthropogenic impact in the area. The construction of the port was carried out between 1899 and 1903; in those times, the breakwater had a length of 1.7 km and a maximum distance from the coast of 1.1 km. A navigation channel towards the port was dredged in 1903 through a sandbank. Since then, many modifications have been carried out in order to deepen and widen the access channels and, finally, to extend the outer port. Significant expansion works were carried out between 1980 and 1985, with the construction of two 4 km long, parallel breakwaters extending about 3 km out to sea. Today, the outer port has a depth of up to 16 m below MLLWS and a connection towards the open sea of 14 m below MLLWS; the port and the channels are thus substantially deeper than the nearshore area where water depths are generally less than 10 m below MLLWS. To conserve the maritime access to the coastal harbours and to the Scheldt estuary, continuous dredging is needed.

**Storm influence on SPM concentrations in the coastal turbidity maximum**

Multi-sensor tripod measurements in the high-turbidity area of the Belgian nearshore zone (southern North Sea) allowed investigating storm effects on near bed suspended particulate matter (SPM) concentrations. The data have shown that during or after a storm the SPM concentration increases significantly and that high concentrated mud suspensions (HCMS) are formed. Under these conditions, about 3 times more mass of SPM was observed in the water column, as compared to calm weather conditions. The following different sources of fine-grained sediments, influencing the SPM concentration signal, have been investigated: wind direction and the advection of water masses; the previous history and occurrence of fluffy layers; freshly deposited mud near the disposal grounds of dredged material, navigation channels and adjacent areas; and the erosion of medium-consolidated mud of Holocene age.

Based on erosion behaviour measurements of in-situ samples, the critical erosion shear stresses have been estimated for different cohesive sediment samples outcropping in the study area. The results have shown that most of the mud deposits cannot be eroded by tidal currents alone, but higher shear stresses, as induced by storms with high waves, are needed. Erosion can however occur during storms with high waves. Data suggest that in order to obtain very high SPM concentrations near the bed, significant amounts of fine-grained sediments have to be resuspended and/or eroded. The disposal grounds of dredged material, navigation channels and adjacent areas with freshly deposited mud have been found to be the major source of the fine-grained sediments during storms. This result is important, as it suggests that dredging and the associated disposal of sediments have made available fine-grained matter that contributes significantly to the formation of high SPM concentrations and high concentrated mud suspensions.
Long-term influence on the distribution of cohesive sediments

Long-term changes in the cohesive sediment distribution of the Belgian–Dutch near-shore zone (southern North Sea) are related to human activities (port construction, deepening of navigation channels, disposal of dredged sediments) and to natural variability, due to tides and meteorological effects. Results are based on the combined analyses of recent and historic (100 years ago) sediment sample information and bathymetric maps. Data processing was based mainly on field descriptions of the samples (consolidation, thickness) and on bathymetric maps of 1866–1911. Results indicate that the distribution of fresh mud and suspended sediment has changed during the last 100 years, due mainly to maritime access works. Most of the present deposition of thick layers of fresh mud (>30 cm) has anthropogenic causes. The results further indicate that erosion of older Holocene mud has increased in recent times and, as a consequence, higher amounts of fine-grained sediments are being released into the southern North Sea today.

Optimising the maritime access to the port of Zeebrugge – A study of water and sediment exchange at the harbour entrance

At Flanders Hydraulics Research in 2009 started a project to examine how an improved maritime access can be created for the port of Zeebrugge. A first study dealing with the water and sediment exchange at the harbour entrance for the existing configuration has been completed. This research primarily used the results of intensive measurement campaigns in situ. Also hydraulic modeling was conducted with a detailed numerical model that was set-up and calibrated in 2006.

In a measuring track across the harbour entrance (see Figure 1), all hydraulic data from two intensive 13-hours through tide measurements, which took place during one spring (31/7/2007) and one neap tide (7/8/2007), were analyzed and synthesized to some characteristic figures. These give a picture of the contribution of the three distinct processes that form the complete water exchange between sea and port at the harbour entrance. It appeared that the main process is tidal filling: 60 to 70% of the total water exchange is due to tidal filling. Then there are the horizontal and vertical circulations, accounting for respectively 20 to 30% and approximately 10% of the total water exchange. The horizontal circulation is caused by a large velocity gradient between the flow outside the harbour and the relatively quiet water flowing between the harbour breakwaters. The vertical circulation is caused by density differences between offshore water and water inside the harbour. This vertical circulation is probably reinforced by the fresh water discharges in the harbour.

These three processes can be simulated with a three-dimensional numerical hydraulic model for the port of Zeebrugge and surroundings that is operational at Flanders Hydraulics Research. Scenario calculations were performed with this numerical model for different boundary conditions regarding tide and salinity. The results of these simulations confirm the figures given above on the relative importance of the three distinct processes and allow to determine the ratios of the three mentioned processes for conditions other than the existing.

Also the sediment exchange through the harbour entrance is quantified. Starting from the results for on the one hand the water exchange and on the other hand intensive sediment concentration measurements during the 13-hours through tide measurements, the sediment exchange could be studied empirically. Relevant overall results
are that approximately 70% of all the sediment that enters the harbour through the entrance stays inside the harbour (siltation), and that about 70% of the total sediment influx occurs in a short period of two hours before high water. This analysis also showed that the most sediment enters the harbour via a zone relatively close to the bottom, in the eastern half of the harbour entrance. As a check, the net sediment influx from these measurements was compared in order of magnitude with the average siltation rate inside the harbour as it is known from the figures of the maintenance dredging. Both figures are roughly similar: there is a net influx of about 5000 TDS per tide to the port of Zeebrugge.

![Figure 1. The location of the measuring track across the harbour entrance (coordinates in ED50 UTM31N)](image)

**Efficiency of dumping locations**

The sediments dredged in the port of Zeebrugge are mostly dumped on the dumping site B&W Zeebrugge Oost, which is located about 4.5 km east of the port. The dredged matter consist of nearly pure mud (> 95%) and is easily resuspended after dumping. Recirculation of the dumped matter towards the nearby dredging places (port of Zeebrugge and Pas van het Zand) is therefore to be expected resulting in an increase of sedimentation and thus a decrease of efficiency of dredging operations. The simulations presented hereafter are a refinement and extension of the previous work. The aim of this study is to investigate the efficiency of existing dumping locations (B&W S1, B&W S2) and the fictive dumping site Zeebrugge West as alternative for the dumping site B&W Zeebrugge Oost.

The study was carried out using numerical models. The currents and surface elevation have been modelled using an implementation of the COHERENS hydrodynamic model to the Belgian Continental Shelf, termed hereafter OPTOS-BCS. The model has a grid of 250×250m². Boundary conditions of water elevation and depth-averaged currents for this model have been provided by the operational models OPTOS-NOS (covering the North Sea and part of the Channel) and OPTOS-CSM (covering the North-West Euro-
The mud dynamics was calculated using a 2D cohesive sediment transport model. The simulations cover a period of 1 month (January 2007) with no meteorological disturbances. Every hour 327 ton dry matter (TDM) of mud is dumped. The results indicate that, generally, all dumping results in recirculation towards dredging areas. A few conclusions can be drawn from these simulations:

- Replacing B&W Zeebrugge Oost by Zeebrugge West and to a lesser extend by tide related dumping reduces significantly the recirculation towards the Pas van het Zand and the port of Zeebrugge.
- Recirculation towards the coastal dredging areas (Pas van het Zand and Port of Zeebrugge) is negligible when dumping occurs on B&W S1 and B&W S2.
- Taking into account the recirculation to all dredging areas, then B&W S2 is the most efficient dumping site.

**Biological and chemical effects of dredge material**

On the Belgian Part of the North Sea, five areas for the disposal of dredged material are designated within 15 km of the coastline. The research of ILVO – Animal sciences – Fishery focuses on the possible effects of dumping of dredged material on the bottom fauna and the sediments, based on semestral monitoring campaigns, in this report concerning the period 2007-2008. The impact evaluation is based on (1) the ecology of three groups of bottom fauna, being macrobenthos, epibenthos and demersal fish, (2) the evaluation of chemical contaminants in the sediment and in different biota and (3) the quantification of biochemical reactions on the concentration of pollutants in animal tissues and the occurrence of fish diseases and parasites in demersal fish. The sampling strategy is based on a control/impact design, whereby the five dumping sites are compared with control areas just outside or in the neighbourhood of the respective dumping sites.

For the biological analysis, 387 Van Veen samples (sedimentology and macrobenthos) and 68 beam trawl tracks (epibenthos and demersal fish) were processed. The chemical analyses were performed on 197 sediment samples and 249 samples of epibenthos and demersal fish; fish pathology was investigated at 68 fishing tracks, whereby from each haul an average of 50 species was evaluated.

The sedimentology of the dumping sites showed temporal and spatial variation within its habitat boundaries. Mainly the local effect of the dumping intensity influenced the median grain size and the mud content, particularly at Br & W S1.

Concerning the chemical effects, a strong similarity in sediment quality was observed between the dumping sites and the control areas. There was no significant difference between impact and control samples regarding chemical effects in neither demersal fish nor epibenthos. This is probably due to the fact that the dumped material generally has a good chemical quality. Most analysed substances occur at concentrations below legal limits and thus hardly influence the chemical quality of the environment at the dumping sites. The chemical quality at the dumping sites and the control areas is probably determined by the chemical composition of the fine fraction cloud in the BPNS at a particular time. This chemical composition is in turn determined by the chemical inputs from rivers (e.g. river Scheldt), commercial ports and Atlantic Ocean water reaching us through the English Channel. This hypothesis needs further investigation.
Severe fish diseases such as ulcers, deformations, nodules and open wounds were rarely found on the investigated (commercial) fish species. The dataset, however, was too limited to show significant effects of dumping of dredged material. Fish parasites were encountered more often, but their abundance could not be attributed to a certain location (due to the migration activity of the fish species itself). Only *Glugea stephani* on dab and *Lernaeocera branchialis* on whiting showed a higher prevalence at the dumping sites in spring and autumn respectively. These data should be followed up in the future to see if these results are consistent.

On the ecological effects, it can be postulated that on dumping sites with low disposal intensities (dumping site Nieuwpoort, BR & W Oostende and BR & W S2) (< 1,000,000 tonnes dry matter/year), the impact on bottom fauna is negligible. Benthic animals are resistant against limited disposal intensities and are able to recover between consecutive dumping events. At BR & W S1 and BR & W Zeebrugge Oost, where the dumping intensities are much higher, a clear impact on bottom fauna was detected. This impact was small, but significant for epibenthos, which is rather mobile and able to recolonize quickly. For macrobenthos, whose sedentary occurrence is strongly related to the sediment type, distinct effects were found. As chemical impact at these sites was negligible, the effects were attributed to the physical process of dumping, suffocation of organisms and changes in sediment composition (e.g. disposal of muddy sediments on a natural sandy bottom). The demersal fish fauna was less influenced by the dumping itself, due to its high mobility, but was rather affected by the reduced prey availability in impacted areas.

![Figure 2](image-url)

Figure 2. Spatial distribution of the univariate characteristics (number of species and density) at the dumping site S1, with indication of the impact and control area (excluding the overall monitoring stations) and the natural gully-bank gradient.

On BR & W S1, where most dredged material was dumped during the period of investigation, the species diversity of macrobenthos and epibenthos was significantly lower than in the control area. The density, biomass and species composition of the macrobenthos was also significantly negatively impacted at BR & W S1 (Figure 2). Benthic species clearly encountered difficulties when the dumping intensity was high and chronic. At BR & W Zeebrugge Oost the impact was mainly reflected in lower densities for macrobenthos and epibenthos. The impact at BR & W Zeebrugge Oost was less severe due to the fact that this area is already naturally characterised by a poor benthic community. The reaction of epibenthos and demersal fish to the dumping activity was probably related to reduced prey availability, but this functional relation needs more detailed investigation (Figure 3).
Compared to Br & W Zeebrugge Oost, Br & W S1 is located in a potentially rich area, i.e. the *Abra alba* habitat, which is characterised by muddy fine sand and a diverse and dense benthic community. The need for more detailed study on the long-term monitoring data of the fauna, linked to the local sedimentology, detailed dumping intensity information and the local morphology and typology of the habitats is clear. The aim of such a study should be to investigate the relation between the changes in the benthic fauna due to the dumping activity and the natural fluctuations in the local heterogeneous environment. Ideally, ecologically sound advices will subsequently be formulated concerning changes in the dumping intensities or re-location of dumping areas due to economical or logistic reasons, taking into account the ecological value of the coastal area and the dumping areas.

It is clear that benthos characteristics in general and the Benthic Ecosystem Quality Index (BEQI) in particular are good indicators for evaluating the impact of dumping of dredged material. The average BEQI scores were lowest for the sites with the highest dumping intensities (Figure 4). The monitoring strategy is adequate, but the sampling intensity can be optimised at certain locations.
Sediment monitoring programme 2007-2008 of the dredging sites

In December 2007, ninety-four sediment samples were taken in the navigation channels, access channels to the harbours and in the harbours. For scientific reasons a few samples were taken along the coast and on the Vlakte van de Raan. These last samples were not taken in previous monitoring programmes (1989/1990 and 2001). The objective of the sampling campaigns is to evaluate the quality of the dredged material over the years. Results are given below in figure 5.

In samples laying close together, a big variation was found in the concentrations. Therefore, at the beginning of 2008, new samples were taken at 13 locations. The number of samples per location was increased and composite samples were made. All previous analysis were done again.

In general, the results of the analyses were the same as in 2007. In most of the samples no significant differences were found. An exception is a sample in Zeebrugge har
bour where the TBT concentration in the composite sample was remarkably lower than in the 2007 analysis.

**Ecotoxicological analysis of the sediments**

The possible ecotoxicity of fourteen samples taken during the big campaign has been investigated. A comparison was being done between the ecotoxicological and physico-chemical results of 2001 and this research, and where possible also with the physico-chemical research of 1990.

Both in 2001 and 2007, negative impact was shown in several samples with several organisms.

This is remarkable since the results of the chemical analyses showed that the samples (except for TBT) had not been polluted strongly and that (except a marked local increase or decrease in the TBT content) no large differences in the pollution degree could be found between 2001 and 2007. For this reason, in the analysis of the data from both years clear attention was given to the possible influence of background contaminants such as sulphide and ammonium and the influence of the granulometry of the sample.

These factors proved to be important. When interpreting the results, negative impacts on organisms caused by the grain size distribution, have not been assessed as toxic, because the grain size is not considered a toxicant. Impact which has been probably caused by raised ammonium and/or sulphide content has been, however, assessed as toxic impact but this impact cannot be considered as an indicator for the presence of anthropogenic contaminants.

The table below gives the comparison between the results of the ecotoxicological tests of 2001 and 2007.
Table 1. Qualitative assessment of the ecotoxicological analyses in 2001/2007

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<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>W03</td>
<td>±</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>(±)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>(±)/+</td>
<td>(+)/±</td>
<td></td>
</tr>
<tr>
<td>W04</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>+</td>
</tr>
</tbody>
</table>

– = no toxic effect ± = medium toxic effect + = severe toxic effect. Bio-assays where the negative effect is (most) probably due to exceeding of the background values are between brackets.

**Qualitative comparison of TBT analysis**

TBT analysis is a difficult exercise, so it was decided that some of the samples from the 2007/2008 campaign are analysed by another laboratory. Besides a few samples were taken from the hopper of the dredging vessels and analysed by both laboratories.

From this exercise it can be concluded that the results of both laboratories are similar and the TBT analysed can be considered as relevant.
1 Dredging and Dumping

1.1 Introduction

To conserve the maritime access channels to the Belgian coastal harbours and to maintain the depth of the Flemish coastal harbours, dredging is needed (Flemish competence) in order to guarantee safe maritime transport. This type of dredging is called maintenance dredging and it is the only type of dredging which is covered by this report.

Most of the dredged material is being dumped at sea except when the quality is suitable for beach nourishment. The last use is called beneficial use of dredged material.

Dumping at sea of dredged material is carried out in accordance with the federal law of 20th January 1999 and a permit is given in accordance with the procedure defined in the royal decree of 12th March 2000. Corresponding to article 10 of this procedure, a “synthesis report” has to be established for the Minister who has the North Sea under his competences. The synthesis report needs to include recommendations which support the development of an enforced environmental management.

In the previous permitting period (April 2008-December 2009) permits were given to the Maritime Access Division who is responsible for maintaining all maritime access channels to the Flemish ports as well as to the Coastal Division of the Agency for Maritime Services and Coasts who is responsible for the maintenance of the Flemish Coastal Marinas.

The international framework for dumping at sea of dredged material is the (regional) OSPAR Convention (1992) and the (worldwide) London Convention (1972) and Protocol (1996). These conventions and their associated guidelines take into account the presence of any contaminants within the sediment and whether some alternative beneficial use is possible.

In implementing these guidelines, e.g. action levels (sediment quality criteria) have to be defined, dumping sites have to be chosen and a permanent monitoring and research programme has to be carried out.

1.1.1 Dredging activities

The dredging companies are assigned after a European tender procedure, which is started by the Flemish authorities. In previous years, dredging years started from April and ended in March, but from 2008 on, dredging years are following calendar years.

The areas to be dredged are divided in accordance with the target depth which is defined in function of the expected vessel types and their maximum draught.

The use of certain dredging technique is dependent upon the site, the hydrodynamic and meteorological circumstances and the nature of the sediment to be dredged. Evaluation is being made on the basis of economical, ecological and technical criteria. In Belgium most commonly trailing suction hopper dredgers are used with a hopper capacity from 5,000 to 10,000 m³.

In the access channels and Flemish harbours, maintenance dredging is virtually continuous throughout the year. Maintenance dredging in fishing harbours and marinas is taking place before and just after the coastal tourist period. A major port—and its con-
nected access channels—with a diversity of customers may need to carry out a capital project every few years to accommodate changes in the patterns of trade and growth in the size of the vessels to be accommodated.

1.1.2 Dumping activities

Quantities permitted

In the former licensing period April 2008-December 2009, four permits for maintenance dredging were granted to the Maritime Access Division as well as three permits to the Agency for Maritime and Coastal Services. The maximum and average attributed quantities which may be dumped at sea per year and per dumping area are given in Table 1.1 and Table 1.2. It should be noted that the permit holder is requested to not exceed the average quantities. The dumping sites are given in the accompanying map at the Annexes.

Table 1.1. Permits for the Agency for Maritime and Coastal Services

<table>
<thead>
<tr>
<th>Permit reference</th>
<th>Dredging site</th>
<th>Type dredging</th>
<th>Dumping site</th>
<th>Yearly permitted quantities TDS (tonnes dry substance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.B. ref. BS/2008/01</td>
<td>* Scheur West&lt;br&gt; * Scheur Oost&lt;br&gt; * Pas van het Zand en CDNB Zeebrugge en Voorhaven Zeebrugge</td>
<td>maintenance</td>
<td>Br&amp;W S1</td>
<td>average: 2,300,000&lt;br&gt; maximum: 2,800,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>average: 6,400,000&lt;br&gt; maximum: 7,150,000</td>
</tr>
<tr>
<td></td>
<td>Total: 11,000,000&lt;br&gt; maximum: 12,750,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.B. ref. BS/2008/02</td>
<td>* Scheur West&lt;br&gt; * Scheur Oost&lt;br&gt; * Pas van het Zand en CDNB Zeebrugge en Voorhaven Zeebrugge</td>
<td>maintenance</td>
<td>Br&amp;W S2</td>
<td>average: 500,000&lt;br&gt; maximum: 600,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>average: 375,000&lt;br&gt; maximum: 450,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>average: 2,000,000&lt;br&gt; maximum: 2,400,000</td>
</tr>
<tr>
<td></td>
<td>Total: 2,875,000&lt;br&gt; maximum: 3,450,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.B. ref. BS/2008/03</td>
<td>* Toegangsvaargeulen Oostende (Stroombankkil, ingangsgul Oostende)&lt;br&gt; * Haven Oostende</td>
<td>maintenance</td>
<td>Br&amp;W Oostende</td>
<td>average: 600,000&lt;br&gt; maximum: 900,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>average: 500,000&lt;br&gt; maximum: 700,000</td>
</tr>
<tr>
<td></td>
<td>Total: 1,100,000&lt;br&gt; maximum: 1,600,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.B. ref. BS/2008/04</td>
<td>* CDNB Zeebrugge&lt;br&gt; * Haven en Voorhaven Zeebrugge&lt;br&gt; * Toegangsgeul Blankenberge</td>
<td>maintenance</td>
<td>Br&amp;W Zeebrugge Oost</td>
<td>average: 3,900,000&lt;br&gt; maximum: 5,500,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>average: 2,100,000&lt;br&gt; maximum: 3,150,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>average: 70,000&lt;br&gt; maximum: 100,000</td>
</tr>
<tr>
<td></td>
<td>Total: 6,070,000&lt;br&gt; maximum: 8,750,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRAND TOTAL</td>
<td></td>
<td></td>
<td></td>
<td>average: 21,045,000&lt;br&gt; maximum: 26,550,000</td>
</tr>
</tbody>
</table>
Table 1.2. Permits for the Agency for Maritime and Coastal Services

<table>
<thead>
<tr>
<th>Permit reference</th>
<th>Dredging site</th>
<th>Type dredging</th>
<th>Dumping site</th>
<th>Yearly permitted quantities TDS (tonnes dry substance)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Br&amp;W Oostende</td>
<td>average</td>
</tr>
<tr>
<td></td>
<td>* Jachthaven van Oostende – RYCO</td>
<td>maintenance</td>
<td>Br&amp;W Zeebrugge Oost</td>
<td>50,000</td>
</tr>
<tr>
<td></td>
<td>* Jachthaven van Oostende – Montgomery dok</td>
<td></td>
<td></td>
<td>50,000</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Total :</td>
</tr>
<tr>
<td></td>
<td>M.B. ref. BS/2008/05</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>* Vaargeul Blankenberge</td>
<td>maintenance</td>
<td>Br&amp;W Zeebrugge Oost</td>
<td>100,000</td>
</tr>
<tr>
<td></td>
<td>* Vlotdok Blankenberge</td>
<td></td>
<td></td>
<td>100,000</td>
</tr>
<tr>
<td></td>
<td>* Spulkom te Blankenberge</td>
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<td>100,000</td>
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<td></td>
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<td>Total :</td>
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<tr>
<td></td>
<td>M.B. ref. BS/2008/06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>* Toegangsgeul Nieuwpoort</td>
<td>maintenance</td>
<td>Br&amp;W Nieuwpoort</td>
<td>70,000</td>
</tr>
<tr>
<td></td>
<td>* Vaargeul en havengeul te Nieuwpoort</td>
<td></td>
<td></td>
<td>200,000</td>
</tr>
<tr>
<td></td>
<td>* Oude Vlotkom te Nieuwpoort</td>
<td></td>
<td></td>
<td>100,000</td>
</tr>
<tr>
<td></td>
<td>* Nieuwe jachthaven te Nieuwpoort</td>
<td></td>
<td></td>
<td>200,000</td>
</tr>
<tr>
<td></td>
<td>* Novus Portus te Nieuwpoort</td>
<td></td>
<td></td>
<td>200,000</td>
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<td></td>
<td></td>
<td></td>
<td>Total :</td>
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<tr>
<td></td>
<td>M.B. ref. BS/2008/ Nieuwpoort</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>GRAND TOTAL</td>
</tr>
</tbody>
</table>

Quantities dumped.

Table 1.3 gives an overview of the quantities dumped at sea since 1991 till March 2007 at the different dumping sites. These quantities were reported on the basis of dredging years (April – March) and are based upon maintenance and capital dredging works. In the previous synthesis report it was recommended to work in future, in particular from 1\textsuperscript{st} January 2006 onwards, with calendar years and make a distinction between permits for maintenance dredging (validity 2 years) and permits for capital dredging works (these permits are granted for the period of working and not linked to this 2-years period).

The decision to work with calendar years for maintenance dredging was the consequence of the European tender for the new dredging contracts which are now following calendar years. In practice, it was decided for this report to start working with calendar years from 2007 onwards. Table 1.4 gives the overview of the quantities of maintenance dredged material disposed during 2007 and 2008. The year 2009 hasn’t been taken up since the year hasn’t finished yet. It should also be noted that from the issuing of the last permits
Beneficial use

To keep the access channel to Blankenberge harbour open, maintenance dredging on a regular basis is needed. Wind and current patterns cause a rapid influx of sand from the nearby beaches and a sand plate is being built up. As a consequence of this, the
The chemical and morphological qualities of this sand are very good. Contamination is virtually non-existent. Within the environmental legislation of the Flemish Region, re-use of dredged material as soil is possible, providing a specific certificate is delivered.

On four occasions, dredged material from the access channel to Blankenberge was used beneficially to reinforce coastal defence on the nearby beaches (table 5).

Table 1.5. Beneficial use of dredged material

<table>
<thead>
<tr>
<th>Period</th>
<th>Beneficially used dredged material (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov. '07 – Feb. '08</td>
<td>69.526</td>
</tr>
<tr>
<td>May '08 – June '08</td>
<td>18.661</td>
</tr>
<tr>
<td>Nov. '08 – Dec. '08</td>
<td>30.884</td>
</tr>
<tr>
<td>Apr. '09</td>
<td>9.588</td>
</tr>
<tr>
<td>Total</td>
<td>122.659</td>
</tr>
</tbody>
</table>

1.2 Alternative dredging methods

1.2.1 Introduction

In the period between 4/05/2009 and 2/06/2009 a pilot project was carried out in the port of Zeebrugge to examine the possibility to reduce of the top silt layer in the port by means of alternative dredging techniques. The test took place in the Albert II dock (see Figure 1.1 for location).

A stationary cutter dredger was used to dredge continuously during longer periods (a few days – a week) on the same location in the dock. Figure 1.1 gives the location of the cutter suction dredger during the test, Table 1.6 gives the start and end times of each dredging period, and the depth of the cutter head.
Table 1.6 Location and depth of the cutter suction dredger.

<table>
<thead>
<tr>
<th>Location</th>
<th>Start period</th>
<th>End period</th>
<th>TAW-z</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4/05/2009 20:30</td>
<td>15/5/2009 14:40</td>
<td>-14.5</td>
</tr>
<tr>
<td>4</td>
<td>28/5/2009 11:45</td>
<td>2/6/2009 8:00</td>
<td>-15.5</td>
</tr>
</tbody>
</table>

The dredged material was transferred & dumped over the western quay wall of the harbour.

1.2.2 Monitoring of the near-field and far-field effects

A series of measurements was set up for the follow-up of the test experiment:

- Daily 33/210 KHz measurements along fixed transects inside and outside the dock;
- Weekly density profiles at fixed location inside and outside the dock;
- Weekly multibeam measurements;
- Continuous tripod measurements near Blankenberge, to assess the impact of the dumped material on the touristic areas;

![Figure 1.2 Location of the measurement locations inside the dock.](image)

Near field effects

No direct influence could be seen on the overall density in the dock: the occurring variations could sometimes be linked to the dredging effort, but a clear relation could not be established. Local density effects could be noted, as illustrated in Figure 1.3.
The dredging effort caused the quick (~hours) creation of a cone-formed crater centred around the cutter head—which was more or less stable during the dredging period.

Influx of bigger quantities of sediment (due to shipping activities or related to an occurring spring tide) caused at some occasions the filling-up of the crater during a short period of time. After relocation of the cutter, the craters disappeared, some of them quicker than the others. At one point in time, three craters occurred simultaneously: one active and two relics. The two inactive craters however disappeared after one day.

The bathymetry of the dumping location was also monitored: no significant changes could be seen in the area. As can be seen in Figure 1.5 the changes in bathymetry before and after the test are not significant.
Figure 1.5 Bathymetrical changes due to dumping of test material.

**Far Field effects**

Data collection was conducted between 5 May and 15 June 2009 using a tripod at Blankenberge site (Figure 1.6). Mounted instruments include a SonTek 3 MHz ADP, a SonTek 5 MHz ADV Ocean, a Sea-Bird SBE37 CT system, two OBS (one at 0.2 m and another at 2 m above bed (mab) and two SonTek Hydra systems for data storage and batteries. The aim of the measurements was to investigate the effects of dumping works on the SPM concentration; the site was chosen near the beach and still accessible with a vessel (depth 5.5 m MLLWS).

The results are shown in Figure 1.6, the measuring period is characterised by generally calm weather; the significant wave height at Bol van Heist is most of the time lower than 1 m, except during three short periods; two at the beginning of the deployment when the significant wave heights are about 1.8 m and one around day 146 with significant wave heights of maximum 1.4 m. The SPM concentration is nevertheless very high (maximum > 3 g/l at 0.2 m above bed (mab) and ±2 g/l at 2 mab) and not typical for spring season, when SPM concentration is usually low (Fettweis *et al.*, 2007a). The near bed concentration remains high during the neap tide around day 150-154, where-
as in the SPM concentration at 2 mab a decrease in concentration is observed. The difference between the 0.2 mab and 2 mab SPM concentrations decreases from day 159 on, thus almost 1 week after the end of the dumping. The effect of spring-neap tidal cycle is visible in the SPM concentration at 2 mab, however at 0.2 mab other processes intervene resulting in e.g. no decrease in SPM concentration between day 150-154. Highest SPM concentrations have been measured during ebb, the difference between ebb and flood peak SPM concentration is highest during spring tide. During previous measurements at the same location an ebb-dominance was also observed, however the difference in magnitude of SPM concentration during ebb and flood was less obvious (Fettweis et al., 2007b).

1.2.3 Conclusions

From this test can be concluded that local, intensive dredging causes a local and temporal lowering of the top mud layer. No systematic, long term effects could be distinguished from the available measurements. The density measurements show a local decrease in the density values, but no effects further on in the dock, as was originally expected.

The dredged material was dumped over the western quay wall. No significant influence on the local bathymetry could be found.

The fact that SPM concentrations measured by the tripod are very high, that the neap-spring induced signal is not always visible in the SPM concentration at 0.2 mab and that the highest SPM concentrations occur during ebb suggest that the dumping operation at Zeebrugge has led to an increase in SPM concentration near the bed just off Blankenberge.

External influences such as the springtide/neaptide cycle, shipping intensity and meteorological conditions are still dominant.
Figure 1.6 Blankenberge site, tripod measurements of 4 May – 15 June 2009 during topslib experiment. SPM concentration at 0.2 mab (SPM1) and 2.0 mab (SPM2). 0° is towards East.
2 Physical aspects related to dredging and dumping

Large amounts of sediments are dredged in the Belgian nearshore area to maintain ships’ access to ports and harbours. The morphological and sedimentological effects resulting from these dredging and dumping works are numerous (OSPAR, 2008). The EU Marine Water Framework Directive provides a framework that embodies the principles of environmental protection, improvement and restoration on an integrated basis. In addition, the WFD specifies that there must be no temporal deterioration in chemical and biological status for many water bodies, and identifies (Annex VIII) ‘material in suspension’ as one of the main pollutants. When human activities occur in habitats characterised by cohesive seabed sediments or by high turbidities, resuspension of material or dredging and dumping can result in higher concentrations of suspended particulate matter (SPM), which can spread over large areas. Alterations of the cohesive sediment distribution are to be expected because infrastructure works, together with dredging and the disposal of sediments, often result in hydrodynamic conditions which are not in equilibrium with the present-day bathymetry. However, the manner in which the system reacts to large engineering works needs to be understood to ensure cost-effective operations at sea, to better gauge the human footprint, and to develop environmental policies aiming at a more sustainable management of the marine environment. Reference situations are rarely available in the marine environment and, therefore, true impacts are difficult to be assessed unambiguously. In addition, the natural variability of, e.g. sediment fluctuations is high in these dynamic settings; as such, the human footprint is difficult to identify.

In this chapter results of different studies are summarized that deal with sediment dynamics and human impact in the Belgian nearshore area. In 2.1 erosion behaviour measurements on mainly cohesive sea bed samples taken near the dredging and dumping areas are discussed (Janssens et al., 2009). 2.2 deals with the long-term anthropogenic impact on cohesive sediment distribution and transport (Fettweis et al., 2009a; 2010), 2.3 describes the water and sediment dynamic around the port of Zeebrugge (Dujardin et al., 2009) and in 2.4 numerical results of the effect of relocation of an existing disposal sites on the recirculation towards the dredging places are presented (Fettweis et al., 2009b).

2.1 Erodibility of muddy sea bottom

With financial support by BELSPO, in the framework of the QUEST4D project, muddy sea bottom samples were taken from the BELGICA platform using a boxcorer. From each boxcore, 3 sub-samples were taken for sediment characterisation (grain-size, bulk density and POC analysis) and measurements of erodibility. The latter was carried out with the SETEG-system, a unique erosion flume developed at the University of Stuttgart. To compare with the SETEG-results, critical shear stress for erosion $\tau_{e,crit}$ was measured also with a CSM (cohesive strength meter, available from VLIZ). However, this technique gave very different results than the SETEG experiments. The CSM, which has a working principle totally different from that of the SETEG flume (a water jet pulse is vertically fired onto the sediment surface with increasing pressure until the onset of erosion is observed) and has a much smaller footprint than the SETEG flume (a few cm$^2$ for the CSM, ~100 cm$^2$ for the flume) is probably not suitable for the measurement of $\tau_{e,crit}$ of North Sea muddy sea bottom.
From the variation of the wet bulk density and of the critical shear stress for erosion $\tau_{e,\text{crit}}$ with depth, mostly a similar pattern can be derived: at the surface, $\tau_{e,\text{crit}}$ is rather low (typical values between 0.3-1.0 Pa), but increases rapidly after a few cm, up to values of several Pa. This suggests a relation with the degree of consolidation: underlying layers are more consolidated and as a consequence more resistant to erosion. Some cores also exhibit a large variation of both $\tau_{e,\text{crit}}$ and bulk density, indicating the presence of different layers in the sample. Some samples seem to indicate a positive correlation between the bulk density and $\tau_{e,\text{crit}}$, although some show no correlation at all, indicating that other parameters (e.g. grain-size, POC) also influence the results.

When only recent mud is considered (categorization of recent mud according to Fettweis et al. (2007c) as having a density value below 1.5 g cm$^{-3}$), an average bulk density of $(1.3 \pm 0.1)$ g cm$^{-3}$ is found for the samples, and an average $\tau_{e,\text{crit}}$ of $(1.9 \pm 0.9)$ Pa. A typical result from the SETEG measurements is shown in Figure 2.1.

The SETEG flume is also capable of measuring the erosion rate $M$ (kg m$^{-2}$ s$^{-1}$): a system of laser lines monitors the volume of the eroding sediment, out of which mass erosion rates can be calculated in combination with the density profile. Erosion rate measurements have been performed at certain depths in several sub-samples. Usually a linear dependency is assumed of the erosion rate on the shear stress exerted by the flow:

$$M = E \frac{\tau - \tau_{e,\text{crit}}}{\tau_{e,\text{crit}}}$$

in which $E$ is the erosion rate parameter. Following this assumption, the erosion rates in Figure 2.2, measured at a certain depth in a certain sub-sample, should be on a straight line, with a slope equal to $E/\tau_{e,\text{crit}}$. It can be observed that some sets of data points indeed seem to exhibit this linear behaviour, although others seem to exhibit no trend at all (could be due to uncertainties inherent in measuring the erosion rates and/or due to the assumption of linear behaviour which could be not a valid approximation in some cases). For “recent mud”, as defined before, the erosion parameter was found to have an average value of 0.03 kg m$^{-2}$ s$^{-1}$, but with a relatively large scatter in the measured data (a $\sigma$-factor of ca. 2).
Figure 2.1. Bulk density and the critical shear stress for erosion using the SETEG system (Janssens et al., 2009).

Figure 2.2. Some results of the erosion rate measurements (Janssens et al., 2009).

It is observed that the results of the measurements (for recent mud) differ a lot from the parameter values used in state of the art numerical models for the BPNS (for the fluffy layer). The differences are shown in Table 2.1. It is suggested to investigate whether changing the parameter values in the numerical models in correspondence with the new laboratory experimental results improves the numerical model results.
Table 2.1. Comparison between new laboratory experimental results (QUEST4D) and typical parameter values used in numerical models for the BPNS for recent mud (fluffy layer, more or less corresponding with the top layer, relatively fresh and not much consolidated muddy sea bottom material).

<table>
<thead>
<tr>
<th></th>
<th>Laboratory experiments on muddy sea bottom samples “recent mud”</th>
<th>Usual parameter values for fluffy layer in state of the art numerical models for the BPNS (Fettweis and Van den Eynde, 2003)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk, wet density</td>
<td>1.2 à 1.4 g cm⁻³</td>
<td>1.2 à 1.4 g cm⁻³</td>
</tr>
<tr>
<td>Critical erosion resistance $\tau_{e,crit}$</td>
<td>1 à 3 Pa</td>
<td>0.5 Pa</td>
</tr>
<tr>
<td>Erosion rate parameter $E$</td>
<td>$0.03$ kg m⁻² s⁻¹ ($/ * 2$)</td>
<td>$0.00012$ kg m⁻² s⁻¹</td>
</tr>
</tbody>
</table>

2.2 Anthropogenic impact on cohesive sediment distribution and transport

The construction of the port of Zeebrugge in the 20th century, including the dredging or deepening of navigation channels and the associated disposal of sediments, represents the most conspicuous anthropogenic impact in the area. The construction of the port was carried out between 1899 and 1903; in those times, the breakwater had a length of 1.7 km and a maximum distance from the coast of 1.1 km. A navigation channel towards the port was dredged in 1903 through a sandbank (Van Mierlo, 1908). Since then, many modifications have been carried out in order to deepen and widen the access channels and, finally, to extend the outer port. Significant expansion works were carried out between 1980 and 1985, with the construction of two 4 km long, parallel breakwaters extending about 3 km out to sea. Today, the outer port has a depth of up to 16 m below MLLWS and a connection towards the open sea of 14 m below MLLWS; the port and the channels are thus substantially deeper than the nearshore area where water depths are generally less than 10 m below MLLWS. To conserve the maritime access to the coastal harbours and to the Scheldt estuary, continuous dredging is needed, see 2.1.

The cohesive sediments in the Belgian nearshore zone consist of Eocene clay, Holocene consolidated mud, freshly deposited mud and SPM. In offshore swales, the thickness of the Quaternary cover is locally less than 2.5 m; in these areas, Eocene outcrops (clay) are to be expected (Le Bot et al., 2005). SPM forms a turbidity maximum between Oostende and the mouth of the Westerschelde estuary. Measurements indicate variations in SPM concentration in the nearshore area of 20–70 mg l⁻¹ and reaching 100 to > 1000 mg l⁻¹; lower values (< 10 mg l⁻¹) occur in the offshore (Fettweis et al., 2007a).

2.2.1 Storm influence on SPM concentrations in the coastal turbidity maximum

Data collection was conducted between April 2005 and February 2007 using a tripod at two sites (Figure 2.3). Both sites are characterised by the occurrence of near-bed Holocene medium-consolidated mud, albeit covered with an ephemeral slightly muddy fine sand layer with a median grain size of about 170 µm. The thickness of the sand layer increases towards the shore. The tripod measuring system was developed to monitor SPM concentration and current velocity (Fettweis et al., 2010). Mounted instruments include a SonTek 3 MHz ADP, a SonTek 5 MHz ADV Ocean, a Sea-Bird SBE37 CT system, two OBS (one at 0.2 and another at 2 m above bed (mab) and two SonTek Hydra systems for data storage and batteries. Three periods have been selected for further analysis to assess storm influences.
Figure 2.3 Bathymetry (m below mean sea level) of the Belgian coastal area. Indicated are the tripod measuring stations (black dots: MOW1, Blankenberge) and the navigation channel (Pas van het Zand and Scheur). Coordinates are in latitude (°N) and longitude (°E).

**Tripod data during storm events**

The data collected at MOW1 in autumn 2005 are presented in Figure 2.4. The measuring period was characterised by 2 days of calm weather followed by a WNW storm with wind velocities of more than 16 m s\(^{-1}\) (7 Bf) and significant wave heights of up to 3.5 m in the coastal zone. A significant increase in SPM concentration occurred almost immediately after the beginning of the storm (day 3-4). This sudden increase in SPM concentration was induced by the exceptional meteorological conditions and partly because the storm occurred after a calm period and around neap tide. After the WNW storm the SPM concentration decreased in magnitude, however both OBS’s still measured very high peak concentrations until the end of the deployment (1 week after the storm). The high minima in SPM concentration measured at 0.2 mab (0.5-1 g l\(^{-1}\)), indicates that a high concentrated mud suspension (HCMS) was formed. It is only days after the storm that the SPM concentrations, measured by both OBS’s, show again similar minima and that the near bed high SPM concentrations have disappeared.
The COHERENS hydrodynamic model has been used to simulate the bottom shear stress during autumn 2005 (22 November – 5 December). The bottom shear stress increases significantly to values of more than 7 Pa during the storm. Without meteorological effects the maxima, occurring during spring tide in the channel towards the Westerschelde (Scheur), reaches about 4 Pa. The difference between model results and shear stress results from ADV can be ascribed to inaccuracies in calculating near-bed shear stress from ADV data.

77 days of data were collected at the Blankenberge site between November 8, 2006 and February 7, 2007. During the periods from 7-18 November 2006 and 24 December 2006 – 8 January 2007 different storms have occurred (Fettweis et al., 2010). The highest SPM concentrations during the November 12 storm have been registered only about one day after the storm at 0.2 mab and about two days after at 2 mab. The near bed data are characterised by very high minima in SPM concentrations (> 0.8 g l⁻¹). The data at 2 mab show only during a short period after the storm an increase in SPM concentration. This indicates that vertical mixing was limited. Similar data have been collected during the storm of December 31. The period before the storm was characterised by low differences in SPM concentration between both OBS. Stratification in SPM concentration has been observed only at the end of the ebbing tide and during slack water and is due to settling of suspended particles. The increase in SPM concentration after the December 31 storm is—similar as observed during the November 12 storm—only detected one day after the storm in both OBS. This increase in SPM concentration
occurred during ebb indicating that the suspended matter has mainly been transported from the NE, i.e. from the mouth of the Westerschelde estuary and in the direction of the wind-driven and the ebb current. Local resuspension of mud layers was at that time of minor importance. A few conclusions can be drawn from the measurements:

- There is a dominant quarter-diurnal (ebb-flood) signal in the SPM concentration time-series. The spring-neap tidal signal can be identified clearly during calm meteorological conditions;
- Considerable variations in SPM concentrations exist during a tidal cycle: maximum concentrations were sometimes up to 50 times higher than the minimum concentrations;
- The very high SPM concentrations measured near the bed are related to storm periods; our data suggest that HCMS occur near the bottom in the coastal turbidity maximum of the Belgian-Dutch nearshore zone; and
- Wind-driven advection can have a significant influence on SPM concentration.

Sources of SPM and processes related to SPM dynamics

The formation of HCMS in wave-dominated areas is well documented in the scientific literature (de Wit and Kranenburg, 1997; Winterwerp, 1999; Li and Mehta, 2000). The origin of the suspended matter in the southern North Sea and in the Belgian-Dutch nearshore zone has been mainly ascribed to the inflow of fine-grained sediments through the Dover Strait, as no high-load rivers exist in the area (Fettweis et al., 2007a). The fluctuation of SPM concentration with time is complex and it is not always straightforward to identify the origin of some of the variations. Based on SeaWiFS images the average mass of SPM over the period 1997-2004 in the turbidity maximum area has been calculated as about 1×10⁶ t. Variations of the order of 30 % occur between spring and neap tides, as also of the order of 40-60 % in-between seasons. Based on the tripod measurements, the SPM mass during storm conditions has been estimated as 3-5×10⁶ t in the same area. An important amount of fine-grained matter has thus to be resuspended, eroded or transported during a storm. Below, some points are discussed in more detail to better identify the possible sources of fine-grained sediments and the processes that result in the significant increase in SPM concentration during storms.

The effect of winds on SPM concentration is variable and depends also on the wind direction and the availability of muddy sediments. Along- or cross-shore advection, enhanced during winds from the SW/NE or NW/SE, respectively, transports water masses with low SPM concentration and higher salinity to the measurement location. During periods with high salinity variations during a tide, a negative correlation between salinity and SPM concentration exists. The data show that during the first 3 weeks of January 2007, SW winds prevailed resulting in advection of high salinity and low turbid water from the English Channel towards the southern North Sea. At the end of January, the wind direction changed towards S-SE and low salinity, high turbidity water originating from the Schelt estuary dominated the signal. Our data show that high SPM concentrations are often more closely related to advection (Velegrakis et al., 1997; Blewett and Huntley, 1998) rather than instantaneous bed shear stress (Stanev et al., 2009).

The largest reservoir of fine-grained sediments in the nearshore area consists of the medium-consolidated Holocene mud. The area where these mud deposits occur in the first meter of the seabed is ~744 km². Erodibility measurements (see 2.1) confirm that
consolidated cohesive bed layers are difficult to erode by only fluid-transmitted stress. The sediments of the mud fields can thus not be eroded under calm meteorological conditions, where the maximum bottom shear stress is about 4 Pa. Near bed shear stresses derived from the ADV data are on average about 12 Pa during the storm of November 2005 at MOW1, end of December 2006 and January 2007. These values indicate that erosion of Holocene mud by fluid-transmitted shear stress can occur and that SPM could have been released into the water column from the Holocene mud fields under storm conditions. Using the Ariathurai-Partheniades formulation for erosion of cohesive sediments, a mean bed shear stress of 12 Pa, a critical erosion shear stress of 10 Pa and an erosion rate of 0.5 g m⁻² s⁻¹ the mass of Holocene mud that can be eroded amounts to 864 t km⁻² day⁻¹. If all the Holocene mud would outcrop then about 0.6 × 10⁶ t per day could have been eroded by horizontal tidally- and wave-induced shear stress during the storm. This is a maximum estimate as large parts of the Holocene mud fields are probably covered by thin layers of sandy sediments.

The movement of recently deposited sediment in the wave boundary layer exposes fine-grained sediment to resuspension when shear stresses become sufficiently high. The numerical model results indicate that, under normal conditions, the bed shear stress in the navigation channels and at location MOW1 or Blankenberge is lower than 4 Pa. The critical erosion shear stresses of in-situ samples in the navigation channels and around Zeebrugge and the disposal ground of Oostende are, below the fluffy surface layer, generally higher than 4 Pa. The deposits of fresh mud below the fluffy layer in these areas forms thus a reservoir of SPM that will only be resuspended during periods with high shear stresses. The total surface of the area where freshly deposited mud is found is estimated based on bed samples as 30 km². The bulk density of these sediments amounts to 1200-1400 kg/m³. If we assume a thickness of 20 cm, then the total mass of mud available for resuspension equals 1.8-3.6 × 10⁶ t. This is of the same order of magnitude as what has been estimated to be in suspension during storms. The data suggest that an important part of the HCMS, measured at the MOW1 and the Blankenberge site, could have been resuspended from the very soft mud deposits in the navigation channels and adjacent areas.

2.2.2 Long-term influence on the distribution of cohesive sediments

To compare historic and recent sediment distributions, it was decided to base the mapping mainly on detailed field descriptions of sediment samples in combination with bathymetric maps. Four characteristic features of cohesive sediment distribution were identified which occur in both the historic and recent datasets: clay pebbles, stiff mud, soft mud and liquid mud. These sediment types can provide an estimate of the relative age of the sediments.

The recent sediment samples were collected between 2000 and 2004. The samples were analysed for grain-size distribution and bulk density (Fettweis et al. 2007c). Following the Coastal Engineering Manual (2002) terminology, these measurements enabled classifying the cohesive sediment samples as “soft to semi-consolidated” (wet bulk density ρ_b = 1500–1800 kg m⁻³), “freshly deposited to very soft consolidated” (ρ_b = 1300–1500 kg m⁻³) and “fluid mud” (ρ_b = ±1100–1200 kg m⁻³).

The historical sediment distribution was mapped based on sediment samples collected by G. Gilson in the first decade of the 20th century (Gilson 1900; Van Loen et al. 2002; Houziaux et al. 2008). The archived inventory of Gilson’s sediment samples contains a
list of 2979 sampling events between 1899 and 1939, of which 90% occurred before 1911. Unfortunately, most of the samples have been lost. However, detailed field descriptions of the sediment samples are still available, which enabled construction of a relative mud content scale. Gilson often indicated additional information on mud appearance, such as “in pieces” or “in lumps”, “hard”, “liquid”, “grey”, “black” or “superficial”, providing clues to relative age, consolidation and origin. Occasionally, additional indications on bottom hardness, as recorded with a depth sounding weight, are given. This information has been taken into account to identify areas with soft to semi-consolidated cohesive sediments and to perform comparisons with contemporary mud samples. Only positive indications are considered as valid data because it is not certain that such features were always appropriately recorded and, thus, their absence could also be due to misreporting.

Historical and recent cohesive sediment distribution

The approach described above enabled construction of a coherent historic map of relative mud distribution along the Belgian coast and the mouth of the Westerschelde estuary (Figure 2.5a). The results show high relative mud contents between Oostende and Zeebrugge. This area became shallower between 1866 and 1911 (Stessels 1866; Urbain 1909), indicating sediment accumulation during that period. Accumulation is observed in a 5-km-wide, coast-parallel mud belt (Figure 2.6). The highest accumulation (±3 m) occurred between Oostende and Zeebrugge, an area corresponding to high relative mud contents at that time. Areas where the seafloor has deepened (> 1 m) are often artificial and situated in navigation channels. These areas are sinks for fine-grained sediments. Further offshore, deepening is probably natural and must be related to erosional processes. Thus, the offshore muds most probably coincide with outcrops of older mud (Holocene or Tertiary).

Figure 2.5b shows the mud content and the distribution of the four major cohesive sediment facies emerging from the sample descriptions, wet bulk density measurements and grain-size analyses. The classification is based on the bulk densities of pure cohesive sediments. This should be used as a first indicator only because small amounts of sand, which often occur in the mud, may increase the bulk density. The four main facies are:

- mud pebbles occurring in a sand matrix or on top of mud layers, indicating erosion (naturally or due to capital dredging works) and transport of clays and consolidated mud layers;
- soft to semi-consolidated cohesive sediments, considered to be largely of Holocene age and possibly including very recent sediments (Fettweis et al. 2007c).
- freshly deposited to very soft cohesive sediments, possibly indicating very recent deposits of thicker mud layers or rewetted older and more consolidated mud. Freshly deposited muds are considered as recent mud deposits related to human activities; they occur in ports, navigation channels and other human-impact areas such as the old disposal ground of dredged material near Oostende. Erosion of these sediments is probably only possible during storm events.
- fluid mud, fluffy layers a few cm thick or thicker layers in ports and navigation channels.
Figure 2.5. Cohesive sediment facies, mud content in the Belgian–Dutch nearshore zone: a historic (Gilson 1900) and b recent. Recent mud content is obtained from grain-size analyses, whereas historic mud content is derived from Gilson’s detailed field descriptions and is reported in terms of a relative scale. The bathymetry in both figures is from 2003.

Discussion

The construction and extension of the port of Zeebrugge and its connections to the open sea, the disposal of dredge spoil, and the morphological evolution induced by these operations have had, and still are having, a substantial influence on the distribution of fine-grained sediment in the study area. Generally, the historic relative mud content corresponds well to the modern quantitative mud content (Figure 2.5). However, some striking differences are noted, in particular higher present-day (relative) mud contents in the nearshore area between Oostende and Zeebrugge. The comparison between the historic and recent data also shows that the distributions of freshly deposited to very soft consolidated mud and of clay pebbles have changed. Possible explanations are discussed below in terms of natural or human-induced morphological changes, dredging and sediment disposal, increased erosion of clayey sediments, and changes in storminess and sea level.
Figure 2.6. Combined long-term trends in mud deposition and seafloor morphology, inferred from detailed visual inspection of bathymetric changes for the period 1866–1911, and from historical sediment sample descriptions (see Figure 2.5). The depth isolines are digitised from the bathymetrical map of Stessels (1866).

From a combination of the relative mud contents derived from Gilson’s meta-information (Figure 2.5a) and morphological changes between 1866 and 1911 (Figure 2.6), it can be seen that mud deposits formerly occupied a narrow belt aligned parallel to the coastline. Comparing the bathymetric maps of 1866/1911 with the observations of Van Mierlo (1908) suggests that these changes started before the construction of the port of Zeebrugge and, thus, are most probably the result of natural morphological evolution. The effect of the first infrastructure works (1899–1903) has potentially reinforced the natural accretional trends, as predicted by Van Mierlo (1897). If these sediments still exist today, then they should fit the category “soft to semi-consolidated mud” and, thus, correspond to modern mud. Deposits of modern mud exist in the vicinity of the port of Zeebrugge. Today, freshly deposited to very soft consolidated thick mud layers (> 30 cm) are less frequent and concentrated mainly near the old disposal ground of dredged material near Oostende, in navigation channels, in harbours, and north of Zeebrugge (Figure 2.5b). In some samples, this mud is deposited on top of soft to semi-consolidated mud, the latter possibly corresponding to the freshly deposited mud layers at the beginning of the 20th century. The deposition of fresh to very soft consolidated mud near the old disposal ground for dredged material started after the 1950s, as revealed by radiometric measurements (Fettweis et al., 2007c). It was probably induced by the morphological changes caused by the disposal of dredged material (Van Lancker et al., 2007).

Clay and mud pebbles, a few cm up to 10 cm in size and of different rounded shapes, have regularly been found in sandy sediments during the last 100 years (Figure 2.5). The rounded shapes indicate that these pebbles have been transported by rolling. flattened shapes may indicate that they have been eroded from layered Holocene mud. Such pebbles are recorded more frequently today, despite the lower sampling resolution. The higher frequency of clay and mud pebble occurrence in the vicinity of the disposal grounds is most probably linked to the disposal of sediments from capital dredging works (Du Four and Van Lancker, 2008). Elsewhere, mud pebbles have been ob-
served regularly in sandy matrices; these could indicate erosion of Holocene mud. Due to the deepening works, Holocene mud deposits more frequently outcrop today.

The port of Zeebrugge and its connection to the open sea, as well as the navigation channels towards the Westerschelde estuary, are efficient sinks for cohesive sediments. Comparison between the SPM transport entering and leaving the Belgian Continental Shelf and the quantities dredged and disposed at sea shows that an important part of the SPM is involved in the dredging/disposal cycle (Fettweis and Van den Eynde 2003). The disposal of fine-grained sediment temporarily increases SPM concentrations in the water column (Van den Eynde and Fettweis 2006). As a consequence, the high turbidity area has shifted further offshore because SPM concentration near the dredging sites has decreased due to deposition, whereas it has increased in the vicinity of the disposal grounds.

Variations in the frequency of storms and in sea level are important controlling factors in the distribution of cohesive sediments and SPM. The WASA Group (1998) reported that the storm and wave climate in most of the North Sea has undergone changes on a decadal timescale, probably related to variations in the North Atlantic Oscillation Index with periods of 17, 7.7 and 2.4 years (Loewe and Koslowski 1994). Regardless of the decadal change in storminess, no statistical long-term trends (> 100 years) have been found for the German Bight (de Jong et al. 1999) or the Belgian part of the North Sea (Van den Eynde et al. 2008). The variation of meteorological conditions can therefore not explain the observed historical changes in cohesive sediment distribution. Based on tide gauge data (Van Cauwenberghe, 1999; Ozer et al., 2008) it is argued that, in 1900 in our study area, the sea level was about 18 cm lower than in 2003, a value which is too low to expect a significant influence on cohesive sediment or SPM distribution by sea-level rise.

2.2.3 Conclusions

Measurements have been collected at two locations in the vicinity of the port of Zeebrugge and its navigation channels. The data have shown that during or after a storm, the SPM concentration increases significantly and that HCMS have been formed. The data suggest that for the generation of very high SPM concentrations near the bed, significant amounts of fine-grained sediments have to be resuspended and/or eroded. The navigation channels and other areas with soft mud have been found to be the major source of the fine-grained sediments during storms. This result is important as it suggest that the deepening of the navigation channels has made available fine-grained matter that contributes significantly to the formation of high concentration mud suspensions. This suggests that HCMS were probably less frequent in the past when anthropogenic activities were limited.

Historical data can provide reliable baseline information for the assessment of long-term human-induced changes in the marine environment. In the Belgian nearshore area, layers of fresh to softly consolidated mud (> 30 cm) reconstructed for the beginning of the 20th century were the result of natural morphological processes. Today, layers of fresh mud are concentrated in areas with high human impact and are not found in the remainder of the nearshore area. The data also indicate that more Holocene mud probably outcrops today than at the beginning of the 20th century and that, as a consequence, erosion of these layers is more prominent today. The Zeebrugge port exten-
sion and associated works have thus in all likelihood increased the amount of fine-grained sediment released into the North Sea, a process on-going today.

2.3 Optimising the maritime access to the port of Zeebrugge

A study of water and sediment exchange at the harbour entrance

This study (Dujardin et al., 2009) investigates the water and sediment exchange at the Zeebrugge harbour entrance using both measurements and results of numerical model scenarios.

2.3.1 Description of the measurements

Measurements were carried out in the area around the harbour entrance of the port of Zeebrugge. For example, during a whole year, parameters—such as flow velocity, turbidity, salinity—were monitored at various fixed locations in and outside the Zeebrugge harbour. Also several 13-hours through tide measurements were conducted along tracks perpendicular to the access channels and within the harbour. Purpose of these measurements was a.o. to detect the occurrence of near-bed high concentrated mud suspensions, to gain insight in density currents between harbour and sea, and their relationship to siltation of the Zeebrugge harbour.

In this study the measurement campaigns along a track across the harbour entrance are analysed (Figure 2.7), which took place during one spring (31/7/2007) and one neap tide (7/8/2007) (IMDC, 2008a; 2008b). Two sets of measuring equipment were used on the same ship. While sailing along the current five vertical profiles of flow velocity and turbidity were taken, using the SiltProfiler. This instrument is composed of three turbidity sensors, each with its own specific range. Sailing against the current, the Sediview technique was used: a 600kHz Workhorse ADCP measured the flow velocity; the backscatter of the signal was used to calculate the sediment concentration within the water column. For each transect a water sample was taken to calibrate both techniques (SiltProfiler and Sediview).

Downside of the Sediview technique is that it requires estimates for the ADCP’s blind zones near the bottom and the water surface and at the edges of the track, because the ship cannot come too close to the harbour’s breakwaters (Figure 2.8). The importance of the method used to estimate the discharges and sediment concentrations in the unmeasured areas is stressed by earlier measurements showing how a significant part of the flood current enters the harbour near the eastern breakwater (Ministerie van de Vlaamse Gemeenschap, 1998; Claeys et al., 2001; Aqua Vision BV, 2004a, 2004b).
Figure 2.7. Map of the measurement locations at the Zeebrugge harbour entrance (coordinates in ED50 UTM31N). The red line indicates the sailed track; the dots indicate the location of the vertical profiles measured with the SiltProfiler (IMDC, 2008a).

Figure 2.8. Unmeasured areas due to instrument and navigation limitations (IMDC, 2008a).
2.3.2 Water exchange

A good knowledge of the water exchange at the harbour mouth is important. Not only does this exchange determine the hydrodynamics within the harbour, the exchange of sediment laden water is also an indicator for sediment exchange and siltation of the harbour. Three physical processes are generally recognized:

- Tidal filling: the water volume flowing in and out the harbour due to the vertical tide.
- Horizontal mixing layer / eddy: the water volume exchanged due to the velocity gradient between the areas in and outside the harbour. In theory water in- and outflux of this component are equal, so there is no net effect from point of view of water exchange.
- Density currents: the water volume exchanged due to the density gradient between the areas in and outside the harbour. In theory water in- and outflux of this component are equal, so there is no net effect from point of view of water exchange.

Defining the ratio of the three main water exchange processes

Although the three main water exchange processes are not totally independent, we will try to estimate the individual contribution of each one to the total water exchange. The method described below is based on Bijlsma (2004).

In order to be able to compare measurements and model results, the vertical plane through the harbour entrance is divided in 5 horizontal layers en 21 vertical columns. Tidal filling is determined as the integral of the instantaneous velocity field perpendicular to the entrance plane, over the surface area of the plane (= instantaneous net exchange). The water exchange in excess of the tidal filling is due to the horizontal mixing layer and density currents. This “excess” is calculated by subtracting the mean flow velocity from the original velocity field. Subtracting the mean velocity per horizontal layer from this “excess” velocity field, results in a velocity field purely driven by the horizontal mixing layer. The total volume of water exchange due to the horizontal mixing layer is calculated by integration of this velocity field. Subtracting the mean velocity per vertical column from the “excess” velocity field, results in a velocity field purely driven by the density currents. The total volume of water exchange due to density currents is calculated by integration of this velocity field. Figure 2.9 visualises the method described above.

Summation of the three calculated volumes (tidal filling, horizontal and vertical exchange) results in a volume bigger than the gross exchange (integral of the absolute value of the velocity field perpendicular to the entrance plane, over the surface area of the plane). This difference is caused by the use of the horizontal and vertical means, which aren’t totally independent. Therefore, the volumes due to horizontal and vertical exchange are rescaled to the excess volume by their mutual ratio. Bijlsma (2004) did not perform this last step.
The study showed a good match between the velocity measurements and the modelled velocities for a spring and a neap tide. The numerical model used is a Delft3d-flow model for the port of Zeebrugge (Bijlsma, 2006), slightly changed to match the harbour lay-out anno 2007. This means the numerical model can be used to investigate the sensitivity of the water exchange processes for different salinity gradients. Four scenarios were used:

- 3D flow; spring tide; constant, uniform salinity (= no salinity gradient).
- 3D flow; spring tide; variable salinity; no fresh water discharge in the harbour.
- 3D flow; spring tide; variable salinity; fresh water discharge in the harbour (1% of tidal volume, which corresponds to normal discharge conditions during a spring tide).
- 3D flow; neap tide; variable salinity; no fresh water discharge possible because lowest water level in the harbour is higher than highest level in the canals running into the harbour.

Results are shown in Table 2.2. The study showed that tidal filling is always the main water exchange process, ranging from 60% to 70% during neap tide and rising to 78% during spring tide if no fresh water is discharged. During the ebb stage tidal emptying is the only process; around slack water horizontal and vertical exchange processes gain importance. The water volume exchanged by the horizontal eddy varies from 20% to 30% of the total exchange volumes, with an instantaneous peak of 50% around maximal flood velocity. Water exchange due to density currents remains low (<5%). Only when a substantial amount of fresh water is discharged into the harbour,
both total water exchange and density exchange increase drastically. The total water exchange increases with 11% and the density exchange doubles.

Figure 2.10. Measured sediment fluxes at spring tide. Sediment influx is only important during the flood stage of the tide and is due to tidal filling (blue curve) and horizontal exchange (green curves). At moments that vertical exchange (red curves) is relatively important there is no sediment flux recorded. Upper: highest sediment fluxes occur near the bottom; 70% of the sediment flux occurs between two hours before high water and high water. Lower: the peak of sediment influx occurs first in the central and eastern part of the entrance, thereafter only in the easternmost part.
Table 2.2. Water exchange through the harbour mouth.

<table>
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<th>horizontal eddy [%]</th>
<th>density current [%]</th>
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Table 2.3. Residual sediment flux into the harbour as measured by the SiltProfiler and the Sediview technique, as calculated from the combined datasets and as reported by the dredging companies (TDM=ton dry matter). (*) from Lauwaert et al. (2006; 2008).

<table>
<thead>
<tr>
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<th>TDM / spring tide</th>
<th>TDM / neap tide</th>
<th>TDM / mean tide</th>
<th>TDM / year</th>
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<td>maintenance dredging</td>
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<tr>
<td>(whole harbour) (*)</td>
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<td>Sediview data</td>
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</tr>
<tr>
<td>combined Sediview and</td>
<td>814</td>
<td>291</td>
<td>520</td>
<td>370,000</td>
</tr>
<tr>
<td>SiltProfiler data</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SiltProfiler data</td>
<td>7229</td>
<td>1799</td>
<td>4173</td>
<td>2,970,000</td>
</tr>
<tr>
<td></td>
<td>7320</td>
<td>3674</td>
<td>5285</td>
<td>3,760,000</td>
</tr>
</tbody>
</table>

2.3.3 Sediment flux

By combining the SiltProfiler and Sediview data a good spatial image of the occurring instantaneous sediment concentrations was obtained. Where the ADCP measurements lack data in the blind zones of the instrument, these were filled up with the SiltProfiler data. Also, the Sediview data range has a maximum at relatively low concentrations; so, for the higher values (near the bottom) the corresponding SiltProfiler data are used to correct the Sediview data. For the areas near the breakwaters estimates were made using nearest neighbour extrapolation. Table 2.3 shows that measured sediment fluxes match well with the averaged amount of maintenance dredging within the harbour. The values of calculated sediment flux based solely on the SiltProfiler data also give a good fit, but should be handled with care. This is because of the interpolation and extrapolation necessary to obtain a total spatial image is based on only five vertical profiles, which introduces great uncertainties. Further on, only the combined SiltProfiler and Sediview data are used. Comparison of influx and outflux shows that up to 70 % of the sediment flowing into the harbour is retained and settles.

Both spring and neap tide measurements show that sediment influx is only important during the flood stage of the tide and is due to tidal filling and horizontal exchange. During the ebb stage there is nearly no outflow of sediment. Figure 2.10 shows water and sediment fluxes during spring tide. The fluxes during neap tide are very alike, only not as strong. The highest sediment fluxes always occur near the bottom, but at the moments that vertical exchange is relatively important there is no sediment flux recorded. In the period between two hours before high water and high water 70 % of the total
sediment influx occurs. This peak occurs first in the central and eastern part of the entrance, thereafter only in the easternmost part.

2.3.4 Conclusions

Both water and sediment fluxes through the Zeebrugge harbour entrance are principally due to tidal filling and the occurrence of a horizontal eddy just inside the harbour. Sediment concentrations are always higher near the bottom and the gross amount of sediment flux occurs there. There is no evidence of important density currents occurring. This is because there is never a significant sediment concentration near the bottom at the moment that vertical exchange processes are of importance.

2.4 Efficiency of dumping locations

The sediments dredged in the port of Zeebrugge are mostly dumped on the dumping site Br&W Zeebrugge Oost (see Chapter 0), which is located about 4.5 km east of the port. The dredged matter consists of nearly pure mud (> 95 %) and is easily resuspended after dumping. Recirculation of the dumped matter towards the nearby dredging places (port of Zeebrugge and Pas van het Zand) is therefore to be expected resulting in an increase of sedimentation and thus a decrease of efficiency of dredging operations. Previous work (Fettweis et al., 2005; Lauwaert et al., 2006) using a 2D hydrodynamic and sediment transport model has suggested that a relocation of the dumping place towards the west of the port and at a same distance from it as Br&W Zeebrugge Oost results in a decrease of recirculation from 39 % to 11 %. The simulations presented hereafter are a refinement and extension of the previous work. The aim is to investigate the efficiency of existing dumping locations (Br&W S1, Br&W S2) and the fictive dumping site Zeebrugge West as alternative for the dumping site Br&W Zeebrugge Oost..

2.4.1 Method

Hydrodynamic and sediment transport model

The currents and surface elevation have been modelled using an implementation of the COHERENS hydrodynamic model to the Belgian Continental Shelf, termed hereafter OPTOS-BCS. The 3D model solves the continuity and momentum equations on a staggered sigma coordinate grid with an explicit mode-splitting treatment of the barotropic and baroclinic modes. A description of the COHERENS model can be found in Luyten et al. (1999). In this application 2D results of current velocity and water elevation together with the bottom shear stress have been used. OPTOS-BCS covers an area between 51 °N and 51.92 °N in latitude and between 2.08 °E and 4.2 °E in longitude. The horizontal resolution is 0.24′ (longitude) and 0.14′ (latitude), corresponding both to a grid size of about 250 m and is thus 3 times finer than the model used in the previous simulation and the port of Zeebrugge is included in the simulation. Boundary conditions of water elevation and depth-averaged currents for this model have been provided by the operational models OPTOS-NOS (covering the North Sea and part of the Channel) and OPTOS-CSM (covering the North-West European Continental Shelf Model) of the Management Unit of North Sea Mathematical Models (see www.mumm.ac.be). Pison and Ozer (2003) have described the validation of the current velocities of OPTOS-BCS using ADCP measurements.
Transport of mud is determined by the settling of mud particles under the influence of gravity and by erosion and sedimentation due to the local current velocity. The model solves the 2D depth-averaged advection-diffusion equation for cohesive sediment transport on the same grid as the OPTOS-BCS model. Erosion and deposition rates are calculated using the formulations of Ariathurai-Partheniades. The model uses the semi-Lagrangian Second Moment Method (Egan and Mahoney, 1972; de Kok, 1994) for the advection of the material in suspension.

The values of the different parameters in the simulations have been determined after calibration, after consultation of published values in literature (Fettweis and Van den Eynde, 2003) and based on the erodibility measurements (see 2.1). Different simulations with different parameter sets have been carried out; one simulation has been selected to illustrate the efficiency of dumping locations. The simulation favours erosion by using a critical erosion shear stress of 0.5 Pa for freshly deposited mud and 0.8 Pa after consolidation. An erosion constant of $0.12 \times 10^{-3}$ kg m$^{-2}$ s$^{-1}$ is used as well as a constant fall velocity of 0.001 m s$^{-1}$ is used. The deposition is not limited by a critical shear stress.

**Scenario's**

The aim of the simulation is to assess the recirculation towards the dredging areas and the area around Zeebrugge if dumping is carried out on Br&W Zeebrugge Oost, Br&W S1, Br&W S2 and on a location west of Zeebrugge at a same distance from the port as Br&W Zeebrugge Oost. Further the effect of tide related dumping on Br&W Zeebrugge Oost and West is simulated. The latter means that during flood the dumping takes place on Br&W Zeebrugge Oost while during ebb dumping is carried out west of Zeebrugge. In total 5 different scenarios are thus considered. For analysis purposes the dredging areas are grouped as follows: port of Zeebrugge (corresponding to CDN, haven en voorhaven Zeebrugge), Scheur West (1-4 in Figure 2.11), Scheur Oost (5, 7-8 in Figure 2.11) and Pas van het Zand (6 in Figure 2.11). It is assumed that all the dumped matter is in suspension during dumping. Further a coastal area (10 in Figure 2.11) is defined.

The simulations cover a period of 1 month (January 2007) with no meteorological disturbances. Every hour 327 ton dry matter (TDM) of mud is dumped. This corresponds to $243.3 \times 10^{3}$ TDM after 1 month (31 days). No mud is entering the domain through the open boundaries and no mud is on the bottom at the beginning of the simulations. The efficiency of a dumping site is estimated by calculated the recirculation towards the dredging area for the different dumping sites.
2.4.2 Results

The averaged mud content on the bottom over the simulation period (expressed in kg m$^{-2}$) is shown in Figure 2.12 and the averaged mud concentration in Error! Reference source not found. for the different dumping sites. It is important to mention that if mud is on average deposited somewhere, that the mud is permanently deposited. The good correlation between the extension of the deposited and the suspended mud indicates that resuspension and deposition as a function of ebb and flood are the controlling processes. If we assume that the density of freshly deposited mud is between 1200-1300 kg m$^{-3}$ then 1 kg m$^{-2}$ corresponds to about 0.8 mm of mud.

The area with – on average – the thickest mud layer is situated on the dumping sites (thickness is about 1 mm) and extends over larger areas, depending on which the dumping site was used. Important differences, which are related to the distance of the dumping site from the shoreline, are visible. Dumping on Br&W Zeebrugge Oost, Zeebrugge West and Zeebrugge tide results in higher deposits of mud and higher SPM concentration in the coastal area near Zeebrugge. The (relatively) high deposition in the port of Zeebrugge, in the navigation channel Pas van het Zand and east of Zeebrugge (Baai van Heist) can be seen from Figure 2.12. Dumping on Br&W S1 and Br&W S2 results in a significant decrease of the suspended mud concentration and mud deposits in the nearshore area. Dumping more offshore will decrease the residence time of the matter in the model domain, as is approximated by the amount of mud in the model after 31 days of dumping (Table 2.4). About 83 % of the dumped matter remains in the model domain after 1 month of dumping on Br&W Zeebrugge Oost, whereas when dumping occurs on Br&W S1 it reduces to 59 %.
Table 2.4. Mass of mud in suspension and on the bottom (in $10^3$ ton and % of total dumped matter) in whole the model domain and in the coastal zone (area 10 in Figure 2.11) after 1 month of simulation and as a function of dumping site. (Zeebrugge-tide: during ebb west of Zeebrugge and during flood on Br&W Zeebrugge Oost).

<table>
<thead>
<tr>
<th></th>
<th>Br&amp;W Zeebrugge Oost</th>
<th>Zeebrugge West</th>
<th>Zeebrugge-tide</th>
<th>Br&amp;W S2</th>
<th>Br&amp;W S1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole domain</td>
<td>202.5 (83 %)</td>
<td>193.4 (79 %)</td>
<td>197.2 (81 %)</td>
<td>192.3</td>
<td>144.1</td>
</tr>
<tr>
<td>Coastal area</td>
<td>90.1 (37 %)</td>
<td>63.9 (26 %)</td>
<td>70.8 (29 %)</td>
<td>0.2 (0 %)</td>
<td>0.0 (0 %)</td>
</tr>
</tbody>
</table>

In B&W Zeebrugge Oost
Figure 2.13 Mud in suspension (10 mg/l) averaged over one month (31 days) when dumping is carried out on the existing dumping sites and on Zeebrugge West. (Zeebrugge-tide: during ebb west of Zeebrugge and during flood on B&W Zeebrugge Oost).
Table 2.5 are shown the amounts of mud deposited in the different dredging areas due to recirculation of dumped matter. Compared to the total amount of dumped matter, these amounts are low and one could conclude that they indicate only a small recirculation. However, given the limitation of even the fine grid model to resolve the relative narrow navigation channels (0.5-1 km wide) and based on the measurements collected during the last years (see 2.2.1), which have shown that fluid mud layers are important in the Zeebrugge area and the limitation of the model to simulate these fluid mud layers, it is very likely that the deposition and recirculation is underestimated. It was therefore decided to assess the efficiency of the dumping sites also on a relative scale supplemented with the quantitative data from Table 2.4. The dumping site Br&W Zeebrugge Oost has been taken as reference. The efficiency of the other dumping sites is expressed relative to this site.
Figure 2.13 Mud in suspension (10 mg/l) averaged over one month (31 days) when dumping is carried out on the existing dumping sites and on Zeebrugge West. (Zeebrugge-tide: during ebb west of Zeebrugge and during flood on B&W Zeebrugge Oost).
Table 2.5), such that 100 % means as efficient as Br&W Zeebrugge Oost and higher (lower) values mean less (more) efficient.
Figure 2.12. Mud deposition ($10^{-1}$ kg m$^{-2}$) averaged over one month (31 days) when dumping is carried out on the existing dumping sites and on Zeebrugge West. (Zeebrugge-tide: during ebb west of Zeebrugge and during flood on Br&W Zeebrugge Oost).
Figure 2.13 Mud in suspension (10 mg/l) averaged over one month (31 days) when dumping is carried out on the existing dumping sites and on Zeebrugge West. (Zeebrugge-tide: during ebb west of Zeebrugge and during flood on B&W Zeebrugge Oost).
Table 2.5. Mass of mud on the bottom (in ton) in the different dredging areas after 1 month of simulation and as a function of dumping site. In total 243.3×10^3 t are dumped (100 % in suspension). Between brackets is indicated the relative deposition in relation to Br&W Zeebrugge Oost. (ZBO: Br&W Zeebrugge Oost, ZBW: west of Zeebrugge, ZB-tide: during ebb west of Zeebrugge and during flood on Br&W Zeebrugge Oost.

<table>
<thead>
<tr>
<th>Area</th>
<th>ZBO</th>
<th>ZBW</th>
<th>ZB-tide</th>
<th>Br&amp;W S2</th>
<th>Br&amp;W S1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheur West</td>
<td>7352</td>
<td>9290</td>
<td>8795</td>
<td>1887 (26 %)</td>
<td>6791 (92 %)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(126 %)</td>
<td>(120 %)</td>
</tr>
<tr>
<td>Scheur Oost</td>
<td>107</td>
<td>48 (45 %)</td>
<td>81 (79 %)</td>
<td>267 (249 %)</td>
<td>1 (1 %)</td>
</tr>
<tr>
<td>Pas van het Zand</td>
<td>4732</td>
<td>2021 (43 %)</td>
<td>2597 (55 %)</td>
<td>103 (2 %)</td>
<td>2 (0 %)</td>
</tr>
<tr>
<td>Port of Zeebrugge</td>
<td>4170</td>
<td>172 (4 %)</td>
<td>2356 (56 %)</td>
<td>2 (0 %)</td>
<td>0 (0 %)</td>
</tr>
<tr>
<td>Total dredging areas</td>
<td>16362</td>
<td>11531</td>
<td>13829</td>
<td>2258 (14 %)</td>
<td>6794 (42 %)</td>
</tr>
</tbody>
</table>

The results show that most of the recirculation occurs towards the dredging areas Scheur West, Port of Zeebrugge and Pas van het Zand; sedimentation in the Scheur Oost is only little affected by the dumping operations.

37 % of the matter dumped on Br&W Zeebrugge Oost is still in the coastal area (10 in Figure 2.11) after 1 month (this reduces to 29 % with tide related dumping and to 26 % when dumping is on Zeebrugge West. It can be expected that a decrease of the amount of mud in the coastal area results in a decrease of recirculation. If we use the amount of mud in the coastal area as a proxy for recirculation then with tide related dumping it reduces by about 20 % and with dumping on Zeebrugge West by about 30 % compared to dumping on Br&W Zeebrugge Oost. Based on the relative data (
Figure 2.13 Mud in suspension (10 mg/l) averaged over one month (31 days) when dumping is carried out on the existing dumping sites and on Zeebrugge West. (Zeebrugge-tide: during ebb west of Zeebrugge and during flood on B&W Zeebrugge Oost).
a similar trend is found, although more obvious. The recirculation towards the port of Zeebrugge and the Pas van het Zand is 56% in case of tide related dumping and only 25% in case of dumping solely on Zeebrugge West compared to the amount when dumping is on Br&W Zeebrugge Oost. Remark that the main advantage of using only Zeebrugge West compared with tide related dumping is the almost complete reduction of recirculation towards the port of Zeebrugge. If the dumping site is further offshore (Br&W S1, Br&W S2) then the recirculation towards the coastal area and thus also towards the coastal dredging areas is negligible (Table 2.4 and Table 2.5).

Dumping in the coastal area (Br&W Zeebrugge Oost, Zeebrugge West and tide related) and on Br&W S1 results always in a deposition of mud in the dredging area Scheur West, more specifically in areas 3 and 4 (see Figure 2.11). The differences between these 4 dumping sites are not very big. It is therefore interesting to notice that recirculation towards Scheur West is significantly reduced if dumping occurs on Br&W S2, however mud deposition increases then on the Vlakte van de Raan.
2.4.3 Conclusions

Generally, all dumping results in recirculation towards dredging areas. The results confirm qualitatively those of a previous study (Fettweis et al., 2005). The simulations have been carried out without density effects (horizontal salinity and temperature gradients) and without meteorological forcing. A few conclusions can be drawn from these “good weather” simulations:

- Replacing Br&W Zeebrugge Oost by Zeebrugge West and to a lesser extend by tide related dumping reduces significantly the recirculation towards the Pas van het Zand and the port of Zeebrugge.
- Recirculation towards the coastal dredging areas (Pas van het Zand and Port of Zeebrugge) is negligible when dumping occurs on Br&W S1 and Br&W S2.
- Taking into account the recirculation to all dredging areas, then Br&W S2 is the most efficient dumping site.
3 Biological and chemical effects of the disposal of dredged material (ILVO)

3.1 Introduction

This chapter summarizes the results of the research undertaken by ILVO-fisheries in the framework of the study towards the ‘biological, chemical and biochemical monitoring of sediment and bottom fauna at the dredged disposal sites off the Belgian Coast’ (cf. protocol ILVO and MOW-aMT of 5 September 2003).

This program focused on three themes:

1. Biological population parameters of the macrobenthos, epibenthos and demersal fish fauna were investigated, in relation to the environment (e.g. sedimentology, depth, salinity). The macrobenthos is, due to its sessile lifestyle, a very good impact indicator. The epibenthos and demersal fish fauna are good indicators for the higher trophic levels. The biological impact monitoring programme has the aim to check if the ecological quality of the marine environment is not affected and to prevent further deterioration of the aquatic life.

2. The histo-pathological part focused on the inventory of fish diseases by commercial fish species. The biochemical part investigates stress-indicators by juvenile dab. This to investigate if the dredge material disposal has repercussion on the food chain safety (fish).

3. The level and trends in heavy metals, PCB’s, OCP’s and PAK’s in sediment and biota were measured within the chemical monitoring part. There is checked if the dredge material disposal does not disturb the local sediment and biota, if the chemical quality of the sediment at the dumping sites does not deviate from the rest of the Belgian part of the North Sea, and if the organisms does not shown higher concentrations of contaminants at the dumping sites.

Samples were taken twice a year, once in spring and once in autumn. This report summarizes the results of the four sampling campaigns in 2007-2008, which are elaborated in Van Hoey et al. 2009. Biological and chemical effects of the disposal of dredged material in the Belgian Part of the North Sea (period 2007-2008). ILVO report

3.2 Study area, sampling strategy and analyses

All sampling locations were distributed in the shallow coastal zone of the Belgian Part of the North Sea (BPNS; limited to approximately 20 km offshore), since all dumping sites are situated in this zone (Figure 3.1). Both biological and chemical monitoring at the dumping sites was done following an impact/control design with impact samples situated within the five dumping sites, while control samples were situated just outside the dumping sites and on locations in the close surroundings (Figure 3.1). Three ecosystem components were monitored: macrobenthos, epibenthos and demersal fish. A sediment core is obtained from every single Van Veen for grain size analysis. This practice enables directly relating sediment conditions to the benthic community of each sample. Chemical contaminants (metals, PAHs, PCBs and chlorinated pesticides) were analysed from an extra sediment sample (fraction < 63 µm), epibenthos and demersal fish.
Macrobenoths can be defined as the organisms that spend most part of their life in the sediment, and that are retained on a 1 mm-meshed sieve. The macrobenthos was sampled with a Van Veen grab (0.1 m²), and sieved on a 1 mm sieve after fixation. In total 387 Van Veen samples were processed. Demersal fish fauna and epibenthos can be defined as organisms living on or in close association with the seafloor, and that are caught representatively and efficiently with a beam trawl. Both ecosystem components were sampled with an 8-meter beam trawl with a fine-meshed shrimp net (stretched mesh width 22 mm in the cod end). 17 samples per season per year were processed. Samples for chemical analysis were packed in alumina foil, deep-frozen and stored as such prior to processing.

Datasets for all ecosystem components were reduced, and a quality control was performed. The difference in biological characteristics were analysed following the impact/control design. For each ecosystem component, community structure was analysed using multivariate techniques available in Primer v6 (Plymouth Routines in Multivariate Ecological Research; Clarke & Gorley, 2001), and structuring factors were determined. Furthermore, univariate measures (density, species richness, biomass and diversity N1) were calculated, and statistically significant measures were determined for the potential structuring factors: season, year or impact, using ANOVA analyses (Statistica 9).

Pollutant concentrations were determined, and averages over the different stations were compared per season, impact versus control sites. For epibenthos and demersal fish, the results were averaged over the different specimens.
Figure 3.1 Overview of the different Van Veen and fish track locations included in this report. All locations were sampled in spring and autumn of both 2007 and 2008. Colour coding indicates usage of samples per dumping site with brown dots showing Van Veen samples from long-term monitoring stations.

### 3.3 Sediment

#### 3.3.1 Introduction

Knowing the physical composition of the sediment is an important prerequisite for both biological and chemical analyses.

Adsorption of chemical contaminants and nutrients is determined by the presence of small silty particles rather than course sand grains, making silt content an important factor for both abiotic and biotic components. Sand is known to have a rather diluting effect on chemical contaminants, as it lacks active spots. Therefore, the sediment is sieved, the fraction < 63 µm is collected, and analysis is performed on this subsample, both for chlorinated organics (pesticides, biphenyls) and metals.
Br&W S1 was the main dumping site used on the Belgian Continental Shelf according to the information on the amount of dredged material dumped daily. The Br&W Zeebrugge Oost received a high amount of dredged material on a regular basis as well. Dumping sites Nieuwpoort, Oostende and S2 are used less frequently, though significant amount of material is deposited at times.

3.3.2 Physical parameters

Dumping site Nieuwpoort

Compared to previous years, dumping site Nieuwpoort was characterized by a less stable and uniform median grain size. Most of the sampling points yielded a value between 250 and 350 µm. Sorting was mostly moderate with a fine to medium sand.

Br&W Oostende

The median grain size on Br&W Oostende varied from about 50 µm to over 300 µm, with the highest values found on the south-eastern side (stations LOO.01-04 and LOO.09) and on the location nearest to the top of the Wenduinebank (LOO.11). Sorting was moderate to poor (LOO.05 in spring 2007) in most stations with exception of the Wenduinebank location (LOO.11) which yielded a moderately well sorted fine sand.

Br&W S2

The median grain size on Br&W S2 varied from about between 200 to 300 µm, with exception of eastward located sampling point LS2.10, which showed a somewhat courser sand (320-350 µm). Sorting was everywhere moderately well and quite stable over the studied period.

Br&W S1

The median grain size on Br&W S1 varied from about between 50 µm at the control locations to over 500 µm in the impact zone (LS1.07 autumn 2008). Silt content was highest in the western control locations with repercussions on the macrobenthic communities (see Figure 3.2). A decreasing trend in silt content was noted in most of the site’s locations.

Figure 3.2 Average silt content ( % ± standard error) on Br&W S1.
Br&W Zeebrugge Oost

The median grain size on Br&W Zeebrugge Oost varied from about between 50 µm at the western control locations to over 400 µm on the highest control point (LZO.12). Silt content was highest in the western control and impact locations (see Figure 3.3).

Figure 3.3 Average silt content (% ± standard error) on Br&W Zeebrugge Oost.

3.3.3 Chemistry

Dumping site Nieuwpoort

Metal content on this location was quite evenly distributed over the different sampling stations. Control stations tend to be higher in metal content and variability of observed concentrations.

Similarly, for sediment seasonal variability is much more important than variability in the dumping site. Values outside the most intense dumping area tend to be higher. Only for DDT and breakdown products, high values were observed on LNP.03 (7.3 µg/kg for DDT, 18 µg/kg for TDE) and LNP.06 (5.2 µg/kg for DDT, 12.1 µg/kg for TDE) in the spring of 2008. This is a flash record, since levels are usually < LOD (limit of detection) on these stations and reference stations were also affected with high DDT levels in 2008. It is difficult to attribute this sudden raise in concentrations to dredged spoil disposal.

Br&W Oostende

Metal concentrations in sediment are very comparable inside and outside the dumping site. Chlorinated pesticides were very low in this region, probably due to the absence of major freshwater sources; biphenyls were slightly lower in the regions with higher dumping intensity. Levels observed there are comparable to those observed in station 230, more offshore. Σ 10 CBs is, however, always < 20 µg/kg DW).

Br&W S2

Metal concentrations seem very little affected by both geographical spreading and dredge dumping. Higher values were observed in the reference stations near the mouth of the river Scheldt, suggesting that the influence of this river as a metal source is equally important.
For organic contaminants, both CBs and pesticides, values were quite low, and higher values were observed in the mouth of the Scheldt estuary. This observation is completely in line with the previous remarks on metals.

**Br&W S1**

Metal concentrations seem also here very little affected by both geographical spread and dredge dumping. Higher values were observed in the reference stations near the mouth of the Scheldt, suggesting that the influence of this river as a metal source is equally important. In stations with intensive dumping, metal concentrations were the lowest observed for the area under investigation.

For organic contaminants, both CBs and pesticides, values were quite low, and higher values were observed on the old disposal site, the former Br&W S1. High values were observed during autumn 2007 on LS1.07 (Σ 10 CBs 41.7 µg/kg DW), together with high DDE values (2.2 µg/kg DW). In the same period, high DDT values (6.7 µg/kg DW) were observed on LS1.04, in a more intensive dumping area. Other chlorinated pesticides were very low, both in control and reference stations.

**Br&W Zeebrugge Oost**

Metal concentrations are somewhat different than for other dumping sites. Higher values for both Hg and Pb are observed in the stations with intensive dumping, compared to reference stations both near and more distant from Br&W Zeebrugge Oost. The contrary is true for Zn and As concentrations, which are higher for less intensive dumping zones and on ZVL and ZEB, especially during autumn 2008.

For organic contaminants, both CBs and pesticides, values are quite low, and higher values are observed in reference stations 140 and 150 near the mouth of the Scheldt (Σ 10 CBs up to 21 µg/kg DW). Higher values for the DDT series were observed on the more intensive dumping area, albeit that values remained low (< 3.5 µg/kg DW.). Exceptionally, only once more than 8 µg/kg DW was noted on LZO.06, were dumping is very low.

### 3.4 Macrobenthos

#### 3.4.1 Introduction

Macrobenthic organisms are, for the largest part of their lifecycle, closely associated with the sediment and have a low mobility. Climate, food supply, predation, but also anthropogenic impacts can have serious repercussions on the benthic populations. Therefore macrobenthos is an appropriate indicator with reference to the state of the marine environment as well as to possible changes of natural or anthropogenic origin.

Knowledge about the physical characteristics (e.g. sedimentology) of the dumping site is important for the evaluation of the impact of the dumping of dredged material. The dumping of material of a certain consistence can change the local sedimentology. Therefore, the habitat characteristics at each dumping site are defined based on the biological benthic community expected in these areas (Figure 3.4). This analysis is hampered by the fact that the impact data are included and possible habitat changes are defined as the habitat potential of this area. This effect is taken into account by linking the observed patterns with the existing knowledge on the spatial distribution of the benthic habitats on the BPNS (Van Hoey et al., 2004, Degraer et al., 2008).
The three main benthic habitats in the Belgian coastal area are the *Abra alba* habitat (diverse and dense benthic community in fine muddy sands), the *Nephtys cirrosa* habitat (less diverse and dense benthic community in well-sorted sandy sediments) and the *Macoma balthica* habitat (benthic community characterised by low diversity and densities and occurring in muddy sediments). Based on the overall analyses, the impact and control samples taken in the context of the evaluation of the dumping sites are linked to each other and to one of the habitat types (Table 3.1).

<table>
<thead>
<tr>
<th>Habitat type</th>
<th>Dumping site Nieuwpoort</th>
<th>Br&amp;W Oostende</th>
<th>Br&amp;W Zeebrugge Oost</th>
<th>Br&amp;W S1</th>
<th>Br&amp;W S2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact samples</td>
<td>LNP 01 – LNP 07</td>
<td>LOO 01 – LOO 07</td>
<td>LZO 01 – LZO 06</td>
<td>LS1 01 – LS1 11</td>
<td>LS2 01 – LS2 07</td>
</tr>
<tr>
<td>Control samples</td>
<td>LNP 08 – LNP 11</td>
<td>LOO 08 – LOO 13</td>
<td>LZO 08 – LZO 13</td>
<td>LS1 17 – LS1 22</td>
<td>LS2 08 – LS2 11</td>
</tr>
<tr>
<td>Control monitoring stations</td>
<td>120 – ZVL 150</td>
<td>ZVL 780 / B08</td>
<td>B031</td>
<td>B032</td>
<td>B041</td>
</tr>
<tr>
<td></td>
<td>B08</td>
<td>B041 / B042</td>
<td>B042</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The difference in covering rate (the dumping intensity) at the five dumping sites on the Belgian part of the North Sea is clear. It varies from a low-to-moderate dumping activity (Nieuwpoort, Br&W S2, Br&W Oostende) towards intense and continuous dumping (Br&W S1 and Br&W Zeebrugge Oost). It is also clear that the disposal intensity is not equally distributed over the impact area and that there is an edge effect in the neighbourhood of the dumping areas at some locations (*cf.* Br&W S1).

The patterns observed concerning habitat characteristics, benthic characteristics and dumping impact are outlined per dumping site.
Dumping site Nieuwpoort

The dumping site of Nieuwpoort consists of fine sandy sediments and is as such situated in the *Abra alba* habitat. The community characteristics at this site show high densities and species richness conform the *Abra alba* habitat in the BPNS (Van Hoey et al., 2005). The monitoring stations 120, 230 and B08, used as control, show the same characteristics. There was no severe impact on the benthos, but density, biomass and number of species showed lower values at impact stations, although not always significantly. No obvious changes in species composition between impact and control were observed (ANOSIM, p-values > 0.05) in both years. These patterns were expected since the dumping intensity was low (Figure 3.8).

Br&W Oostende

Br&W Oostende is situated within the *Macoma balthica* habitat, characterised by muddy sediments, and a poor benthic community. The single control station for this area is ZVL, which is a muddy station close to Zeebrugge. No differences in benthic community characteristics were detected between control and impact area, despite the fact that Br&W Oostende was used in the period 2007-2008 (Figure 3.8). This is mainly due to a naturally occurring poor community.

Br&W Zeebrugge Oost

Br&W Zeebrugge Oost is situated within the *Macoma balthica* habitat. This area is distinguished by instable, sandy mud and a poor benthic community. The main species occurring in this area are opportunistic polychaetes (Cirratulidae species), the bivalve *Macoma balthica* and oligochaetes. The impact of the high dumping intensity (Figure 3.8) in this area is less pronounced due to the naturally less diverse and dense benthic life, which is already adapted to unstable conditions (cf. Br&W Oostende). Nevertheless, a slight impact was detected in the dumping area, which means that the benthic community suffers from the dredge disposal. This effect was most pronounced in autumn, where the densities of the few species occurring were much lower in comparison to the control (Figure 3.5). This indicates that the normal seasonal recruitment pattern, expecting high densities in autumn, was disturbed. The number of species found in the impact only differed from the control for autumn 2008 (Figure 3.5).

Br&W S2

Br&W S2 is characterised by sandy sediments with very low mud content and as such designated as *Nephtys cirrosa* habitat. The characteristic species are the catworm *Nephtys cirrosa* and the burrowing amphipod genus *Bathyporeia*. In this area, no im-
impact was detected despite the medium dumping intensities (Figure 3.8). More investigation is needed on the nature and amount of the dredged material, the spatial extent of the dumping activities, and the resilience of the benthic fauna, to understand the effect of dumping at this site.

**Br&W S1**

Br&W S1 is located on a natural gradient of the gully-bank system north west of the Vlakte van de Raan. Consequently, this site is characterised by *Abra alba* habitat in the deeper part, whereas the shallower part shows more similarity with the *Nephtys cirrosa* habitat. Additional to this natural gradient, the site receives the highest dumping intensities on the BPNS (Figure 3.8). All these factors create a heterogeneous habitat. The control samples selected for this site are representative for the two habitat types covering the natural heterogeneity of this area.

![Figure 3.6. Average Number of species and density (± standard error) of the benthos in spring and autumn 2007-2008 of impact and control samples at Br&W S1. ■ is significant, ■ is not significant.](image)

A clear dumping impact was found at this site in the years 2007 and 2008, reflected in significantly lower values in density, biomass and number of species between the impact and control areas in all years and seasons (Figure 3.6). The species composition did not significantly change over the years or seasons.

![Figure 3.7. Map of Br&W S1, with indication of the dumping intensities over the period 2007-2008 and the average number of species and densities (± standard error) at each sample location.](image)

The dumping intensity within the Br&W S1 was unequally spread which a much higher intensity in the western part. This was not clearly detected in the benthic parameter differences between the western and eastern part of the site (Figure 3.7). This may be because dumped material goes into suspension, causing an impact further away from the dumping location. The dispersal extent of the suspended sediment depends on the intensity of the currents at the moment of dumping. The effect of sediment dispersal manifested as a decrease in the species richness not only at the locations with the highest dumping intensity, but also in their vicinity. Based on these results, it is recom-
mended to invest in a more detailed study of the link between dumping intensity and long-term biological patterns, and of the natural biological gradient and ecological value of this area. Based on this information, advice can be formulated regarding management and impact reduction.

3.4.2 Indicator evaluation (BEQI).

The Benthic Ecosystem Quality Index is used to scale the degree of impact due to the dumping activities. The BEQI is designed to evaluate deviations in density, biomass, number of species and species composition between impact and control areas (www.beqi.eu; Van Hoey et al., 2007). In Figure 3.8, the average BEQI scores (average of the EQR score of biomass, density, number of species and species composition) of the autumn samples are shown.

![Figure 3.8](image)

Figure 3.8. The average BEQI EQR score for autumn 2007-2008 (left axis) and the dumping intensities from maintenance dredging (right axis) for the respective years.

The BEQI scores were lowest for the sites with the highest dumping intensities (expressed in total tonnes dry matter). Based on the indicator analysis, the Br&W Zeebrugge Oost and Br&W S1 were impacted in autumn 2007-2008. The BEQI scores at each site reflect very well the changes in benthic characteristics between control and impact area.

3.5 Epibenthos

3.5.1 Ecology

When considering all samples taken for epibenthos in the framework of the impact assessment of dumping, geographical location determines the clustering of the samples. This clustering roughly corresponds to the macrobenthic habitat types classified in the different areas. Br&W Zeebrugge Oost, Br&W Oostende and their respective reference samples are closely related in species composition, and were characterised by low densities, biomasses and diversities. These sites are situated in the macrobenthic *Macoma* habitat, a relatively poor community characterised by muddier sediments (see Macrobenthos). These poor communities are mainly influenced by the Western Scheldt and by the ports of Zeebrugge and Oostende on the north-eastern part of the Belgian coast. This is reflected in a higher turbidity of the water, a higher concentration of mud particles in the water and the sediment composition of this area. Br&W S1 and dump-
ing site Nieuwpoort plus respective reference areas also closely resembled each other in species community. These sites were characterised by high values for density, biomass and diversity and are located in the rich *Abra alba* macrobenthic community. The Br&W S2 is transient between these two clusters with intermediate density, biomass and diversity corresponding to the macrobenthic *Nephtys* community.

The geographical location being the dominant structuring factor, further impact assessment was performed per site.

![MDS plot with indication of dumping area](image)

**Figure 3.9**: MDS plot with indication of dumping area (both impact and control samples).

At the local scale, seasonal variation is the dominant factor explaining most of the variation in the community structure. Mostly, species composition between seasons was very similar, but densities were generally much higher in autumn than in spring. Notwithstanding this natural variability, a dumping impact could be detected on Br&W Zeebrugge Oost and Br&W S1; these sites were also the sites with the highest dumping activities.

**Br&W Zeebrugge Oost**

No impact was detected on the species composition, indicating the same species pool being present. Significantly lower densities however were observed due to disposal of dredged sediment. Especially the common shrimp (*Crangon crangon*) was impacted by the dumping activity with significantly lower densities in the dumping area.

![Cumulative average density](image)

**Figure 3.10**: Cumulative average density (Ind/1000 m²) of the different taxa for the control and impact area of Br&W Zeebrugge Oost in spring and autumn.
**Br&W S1**

A significant effect of dumping on species richness was observed at this dumping site. A lower number of species was present in the impacted area. Some species, with *Epitonium clathrus* (Wentletrap) as most conspicuous, were only present in the control samples and not in the impact samples. Possibly, dumping causes this trend but follow up is necessary to confirm this observation. Although, no significant effect was observed in the multivariate pattern, there was a clear separation between impact and control samples in autumn. This is probably caused by higher densities in the control area in autumn compared to spring.

![Species richness for impact and control area of Br&W S1 in both spring and autumn.](image)

For the other dumping sites, no impact effect was observed and this could be expected since these sites were not actively or less intensively in use for dredge disposal.

Even though epibenthos is mobile, and is expected to recolonize the impacted areas quickly, there is a measurable effect on this ecosystem component in the two most impacted dumping sites. These are also the only sites were a macrobenthos effect was detected, and as macrobenthos is an important food source for many epibenthos species, the epibenthos is probably reacting on the impoverishment of the macrobenthic community. This possible coupling warrants a follow-up.

### 3.5.2 Chemistry

Chemical analysis was performed on bivalves, starfish, sea anemone, brown shrimp, hermit crab and swimming crab. Results are averaged per zone. It was always checked if the sample composition had a major impact on the averaged result, and if so, this was mentioned.

Metal concentration in epibenthic species shows considerably more variation between sites than between impact en control sites. The influence of the Scheldt as a source is very important. Pb and Cr showed high variation, what might be caused by a major atmospheric contribution. Bivalves seem the most useful indicator organisms for metal accumulation.

PCB concentrations were not elevated, and only once reached over 20 µg/kg WW. Σ DDT was always less than 20 µg/kg WW. Very comparable results were noted between impact and control zones, the latter being mostly slightly higher in concentration.
Br&W Zeebrugge Oost

There was very little variation in metal concentration during spring: Pb was higher in the impact zone, Cr was higher in the control zone. The variation was much higher in autumn, with almost double values in the control zone compared to impact. Especially Fe values are high (Figure 3.12).

For PAHs, there was considerable variation in concentration. During spring, exceptionally high values were noted in the impact zone. The variation was much lower in autumn, with almost ten times lower values in the impact zone compared to spring, while an increase was noted in the reference zone. Values in control areas are always low to very low (Figure 3.13). Few different species are caught in the impact zone, and averages are dominated by bivalves, known for their PAH accumulating potential.

For Σ 10 PCBs, concentration was close to 13 µg/kg WW, except during spring on the control site, where 22.6 µg/kg WW was noted. Values for Σ DDTs were around 1 µg/kg WW (Figure 3.14). Since chlorinated organics are preferentially analysed, there were more species involved compared to PAH analysis.
Figure 3.14. Average organics concentrations in different epibenthic species per zone for spring and autumn (in µg/kg WW) on Br&W Zeebrugge Oost.

**Br&W S1**

Very little variation in concentration between zones during spring was found, although Pb was higher in the control zone. The variation was much higher in autumn, with 50% higher values in the impact zone compared to control. Especially the drop in values in the control zone in autumn with respect to all other values is striking (Figure 3.15).

Figure 3.15. Average concentrations of metals in different epibenthic species per zone for spring and autumn (Fe, Zn and Cu in mg/kg, Cr, Cd, Pb and Hg in µg/kg) on Br&W S1.

For PAHs, there was very little variation in concentration during autumn, with slightly lower values in the impact zone compared to control. No specimens for chemical analysis were available in the impact zone during spring (Figure 3.16).
For chlorinated organics, there was very little difference between levels in impact and control zones. During autumn, around 50% higher values are noted. Values in the impact zone are slightly higher compared to control. (Figure 3.17).

3.6 Demersal Fish

3.6.1 Ecology

To estimate the impact of dumping dredged material on demersal fish, a general analysis of all fish data was done to get an overview of the major actors. Geographical location (dumping area) and season are the important structuring factors, explaining the variation in the data.

Br&W Oostende (LOO), Br&W Zeebrugge Oost (LZO) and their neighbouring control areas are most closely related concerning species composition. They were characterised by low values for density, species richness and diversity. Dumping areas Nieuwpoort (LNP), Br&W S1 (LS1) and their neighbouring control areas also show resemblance in species composition with higher values for density, species richness and diversity. Br&W S2 (LS2) shows intermediate values for these univariate parameters.
The characterisation of the fish communities corresponds well with the characteristics of the epibenthic and macrobenthic communities.

Furthermore, for all sites, seasonal differences were observed with mostly higher values for density, species richness and diversity in autumn compared to spring. Moreover, the species composition in autumn mainly consisted of flatfish (Pleuronectiformes), whereas in spring, gobies (Gobiidae) were dominant.

At the local scale, seasonal variation is the only significant structuring factor for species composition and the univariate parameters. Although no significant dredging impact was detected, there are some indications that demersal fish might react to the changes in the macrobenthic and epibenthic communities in Br&W Zeebrugge Oost and Br&W S1.

**Br&W Zeebrugge Oost**

Although no significant effect of dumping was detected, there were lower densities in the impact areas. This could be related to lower densities of epibenthos and macrobenthos, which serve as food sources for demersal fish.
Despite Br&W S1 displaying the highest dumping activity, no significant impact on demersal fish was observed. Still, Figure 3.20 indicates lower density values in impact areas. This again could be a reaction to the decrease in density of the macrobenthic and epibenthic communities.

![Figure 3.20. Cumulative average density of the different taxa for the control and impact area of Br&W S1 in spring and autumn. Density (Ind/1000m²)](image)

Since demersal fish are very mobile organisms, recolonisation is expected to be swift. The results indicate indeed no significant impact of dumping. However, since sampling replication is small, conclusions should be nuanced. Therefore, an adaptation of the sampling strategy, especially in the most impacted areas, is recommended.

### 3.6.2 Chemistry

Chemical analysis was performed on dragonet (*Callionymus* spp.), goby (*Pomatoschistus* spp.) and hooknose (*Agonus cataphractus*). Results were averaged per zone. Variation of the metal concentration in fish species showed considerably more variation between sites than between impact and control sites. The influence of the Scheldt as a source is very important. Pb and Cr show high variation, what might be caused by a major atmospheric contribution. PAHs in fish are readily metabolised, as extensively described in open literature, so observed levels are negligible. Studies are on-going on how the impact of these substances on fish species can be quantified.

Organic contaminants were found in reasonable concentrations (< 20 µg/kg WW for $\sum$ 10 PCBs). Chlorinated pesticides were hardly detectable, except for the DDT series (DDT, DDE and TDE). In general, values in impact sites were lower than those found in control sites.

**Br&W Zeebrugge Oost**

For metals, there was very little variation in concentration during spring. Pb was higher in the impact zone, Cr was higher in the control zone, as was the case for epibenthos. The variation was also low in autumn, and the concentrations even 30% lower. In both seasons, metal concentrations were higher in control zones compared to impact zones (Figure 3.21).
Neither dragonet, goby nor hooknose were found in sufficient amounts on Br&W Zeebrugge Oost and neither on control sites to carry out chemical analyses.

**Br&W S1**

There was very little variation in metal concentration during spring, the variation in Fe was responsible for most of the difference. The variation was much higher in autumn, with three times higher values in the impact zone compared to control. This was mainly due to very high Cr levels in autumn in the impact zone. Especially hooknose can contain remarkably high levels of chromium, up to 13 mg/kg WW (Figure 3.22).

For organic contaminants, there was very little variation in concentration during spring and autumn, with slightly lower values in the impact zone compared to control. Values in autumn are approximately half the values observed in spring (Figure 3.23).
3.6.3 Fish pathology

The aim of this epidemiological study is to monitor and compare the prevalence of diseases and parasites of demersal fish on dumping sites and some reference zones on the Belgian Part of the North Sea (BPNS). Therefore, a large number of infectious and parasitical anomalies of the epidermis, the gills and the mouth of several fish species were investigated. Especially ulcers, skeletal deformations, nodules and lymphocystis can provide valuable information on changes in environmental health and may act as an “alarm bell”. In this report, the observations for spring and autumn 2007 and 2008 are described.

The sampled zones include reference zone 1: the coastal zone of the east of the BPNS (Steendiep, Vlakte van de Raan, Gootebank). Reference zone 2 includes the coastal zones in the west of the BPNS (Westdiep, Oostende bank, Oostdyck, Buitenratel en Kwintebank). The third reference zone includes the more Nordic zones Scharrebank, Bligh bank, Fairy bank, de Hinderbanks and the open sea locations. The data of the dredge Br&W Zeebrugge Oost, Br&W Oostende and Br&W S1 were considered as impact area, as they showed the highest impact intensities.

Diseases

Severe diseases such as skin ulcers, nodules, skeletal malformations and lymphocystis, which might indicate effects of pollution, were rare on the investigated zones of the BPNS. Acute, healing and healed ulcerations were found on dab (*Limanda limanda*), sole (*Solea solea*), flounder (*Platichthys flesus*) and cod (*Gadus morhua*) in very low frequencies (between 0.15 % and 4.34 %). Epidermal papilloma (Figure 3.24) could only be detected in dab and plaice and were all stage 1 lesions (less than 4 lesions per individual). Liver nodules were detected in all the sampling zones. The occurrence was very low and varied between 0.17 % and 2.38 %. Lymphocystis (Figure 3.24) is an important disease and has a viral aetiology (Iridovirus). The disease was not detected during 2007 and 2008 for the different fish species. Skeletal deformations were registered on dab and whiting in very low frequencies (between 0.12 % and 1.18 %). No differences in the occurrence of fish diseases could be detected on the basis of the data between the dredge dumping sites and the reference zones.
Figure 3.24. Epidermal papilloma (left) and Lymphocystis (right).

Parasites

Most of the observed anomalies are due to parasites. The most common parasites on fishes on the BPNS are the externally attached copepods, such as *Clavella* on roundfish and *Acanthochondria* spp. (Figure 3.25) and *Lepeophtheirus* spp. on flatfish. These parasites are considered harmless. Especially flounder was host to *Acanthochondria* spp. and *Lepeophtheirus* spp. with frequencies that can reach up to 70%.

Figure 3.25. *Acanthochondria cornuta* (left) and *Stephanostomum baccatum* (right).

The overall prevalence of the trematode, *Stephanostomum baccatum* (Figure 3.25) was very low. In most of the cases, only one or two individuals were present per fish. The skin parasite *Cryptocotyle lingua* (trematode) was present in variable concentrations on roundfish and especially on whiting and pouting. The parasite of the intestines, *Glugea stephani*, was mainly present on dab. The highest prevalence was observed on the dumping sites (15.41%) in autumn (Figure 2.17). The parasitical copepod, *Lernaeocera branchialis* was recorded on the three observed roundfish species whiting, cod and pouting. The occurrence varied according to species, sampling place and period. Whiting showed a higher prevalence on the dumping sites in spring (Figure 2.17).
To conclude, the presence of the parasites showed considerable variation in spatial and temporal distribution. In most of the cases, they could not be related to a specific zone. However, *Glugea stephani* on dab and *Lernaeocera branchialis* on whiting showed a higher prevalence on the dumping sites in spring and autumn respectively. These data should be followed up in the future to see if these results can be repeated.

Finally, it is important to point at the effect of migration on the observed species. On the basis of the migratory properties, flat fish species were chosen as monitoring organisms. The results can, especially for round fish species, be influenced by migration. Therefore, the results rather reflect the health condition of a big area instead of smaller zones like the dredge deposit zones. Nevertheless, some important regional differences in parasitical affection could be observed.

### 3.6.4 Biological effects of contaminants on the BPNS: EROD and GSH-t activity as biochemical indicators of pollution.

The Institute for Agricultural and Fisheries Research (ILVO) has been involved for years in monitoring the effects of pollution on living organisms. Within this biological effects monitoring, major emphasis is put on the effects of introduction of organic compounds such as polycyclic aromatic hydrocarbons (PAH’s) and polychlorinated biphenyls (PCB’s) by dredge spoil dumping on the Belgian Part of the North Sea (BPNS). The effects of these substances in living organisms can be studied through the up-regulation of enzymatic activities involved in biotransformation of pollutants following their binding on the arylhydrocarbon receptor (Ar-H receptor). Up-regulated enzyme activities may serve as “early warning” signals for pollution.

For the past 10 to 15 years, dredge spoil dumping sites such as Br&W Zeebrugge Oost, Br&W S1, Br&W S2, Br&W Oostende and dumping site Nieuwpoort on the BPNS along with the Shipping route to Zeebrugge have been subjected to monitoring of the activity of the EROD (Phase I biotransformation enzyme) and GSH-t (phase II biotransformation enzyme) enzymatic activity in freshly prepared dab (*Limanda limanda*) liver homogenates. Results unravelled the different effect of PAH’s and PCB’s on the two enzymatic activities and allowed determination of a baseline and revealed a clear seasonal effect on EROD induction. A significant statistical effect of the chemical concentrations of PAH’s and PCB’s and the induction of EROD and GSH-t induction between the dumping zones and the reference zones, however, was never established. It is unclear if this is due to less polluted dredge spoil or to its rapid distribution over a large part of the BPNS after dumping.

Figure 3.26. Prevalence of *Glugea stephani* on dab (left) and *Lernaeocera branchialis* on whiting (right).
In 2007-2008 new equipment was installed and measurements could not be performed on fresh samples. Within this period, analysis protocols were optimised and the lab participated, together with 9 other laboratories, in an international inter-laboratory EROD calibration exercise organised by BEQUALM (Biological Effects Quality Assurance in Monitoring Programs). The ILVO biochemical monitoring lab satisfactorily met the assessment criteria, carried out according to the iso43 guidelines, for all samples. In 2008, tests were conducted to study the up-regulation of EROD and other variants such as MROD and PROD in invertebrates. The measured activities were very low and further optimisation is necessary for practical use.

In conclusion it can be stated that EROD is a very sensitive and international accepted tool to use for the detection of biological effects of organic contaminants such as PAH's and PCB's. It still focuses however on only one part of the biological effects and therefore it is recommended to build out the biochemical effects monitoring with newer tools such as histology (on liver, spleen, gonads and kidney's), 'omics' research on liver and DNA adducts. In the following years ILVO will continue its work on the adaptation of assessment criteria for these biomarkers in close cooperation with the ICES working group on biological effects of contaminants (WGBEC).

3.7 Conclusions

Five dumping areas are demarcated on the Belgian Part of the North Sea (BPNS). ILVO investigated the ecological and chemical effect of dumping on the fauna and the sediment. Ecological impact assessment focused on possible changes in the ecosystem by monitoring three ecosystem components: demersal fish, epibenthos and macrobenthos. Chemical impact assessment focused on the evaluation of possible chemical contamination of sediment and fauna. The monitoring strategy followed a control/impact design.

- As demersal fish are mobile organisms, and thus able to escape fast, they did not seem to suffer from dumping. Epibenthos are relatively mobile organisms, and more closely associated with the sediment, and a small, but measurable effect was detected in the heaviest impacted sites. Macrobenthos is a sedentary ecosystem component, in close association with the sediment, and as such the best indicator

Figure 3.27. Seasonal variation of EROD and GSH-t activities in dab liver from the BPNS
to measure dumping effects. Macrobenthos was the ecosystem component where clear impact effects were measured. The effect on the fauna was not related to chemical contamination of the dumping sites, but rather to the physical aspects of dumping (smothering of the fauna, changes in sedimentology). The following conclusions about the dumping activities on the BPNS can be made: On the sites with the lowest dumping intensity, dumping sites Nieuwpoort, Br&W Oostende and Br&W S2, no impact of dumping was detected on the fauna. The fauna seemed to resist dumping or to recover fast from the current dumping activity.

- It is obvious that the benthic macrofauna is a good indicator for studying the impact of dumping activities on the local habitat. It is known that the benthic community can partly cope with sediment coverage, yet it suffers from chronic dumping activities (Rees et al., 1992; Whomersley et al., 2007).

- On the Br&W S1, the site with the highest dumping intensity, significant adverse effects on macrobenthic and epibenthic species richness, and macrobenthic density, biomass and species composition were detected. Results indicate that the effects were due to physical activities, since no chemical adverse effects were detected. More detailed investigations are necessary, since Br&W S1 is situated in a potentially rich benthic area (Abra alba habitat) where high chronic dumping intensities should be avoided. Results of the integration of long-term monitoring data, sedimentology, detailed impact intensities and the local morphology, will be used to find stronger links between the observed faunal changes, natural variability and the dumping intensity in this heterogeneous environment. When the impact appears to be chronic, a discussion is necessary in the technical working group to define measures to tackle the problem, and in the future, even to consider relocation of this site.

- For Br&W Zeebrugge Oost, a significant dumping impact was detected as well with lower macrobenthos and epibenthos densities in the dumping site. However, the impact was less severe, because this area is naturally characterized by a poor benthic community.

- The chemical quality of sediment on dredged spoil disposal sites was quite similar to that on control stations. This leads to the conclusion that this cannot be the cause of ecological impact. In line with this observation, the chemical perturbation of demersal fish and epibenthic species is not significantly different from that of control sites. There are two possible explanations for this phenomenon: either the quality of the dredged spoil is good, since it consists of relocated sediments (not or slightly contaminated), or the cloud of silt covers, due to hydrodynamic transport, such a vast area it is hardly possible to distinguish between disposal sites and control stations. There is some evidence pointing out that the former is more probable.

- Severe diseases like ulcers, deformations, nodules and open wounds were rare, parasites were more often encountered, but could not be attributed to a location. Only Glugea stephani on dab and Lernaeocera branchialis on whiting showed a higher prevalence on the dumping sites in spring and autumn respectively. These data should be followed up in the future to see if these results can be repeated.

The monitoring strategy that was used to detect impacts at the dumping sites was adequate, but some fine tuning is needed to make it more time and cost effective, regarding the aims of the global monitoring program.
4 Sediment monitoring programme 2007-2008 of the dredging sites

4.1 Introduction

In December 2007, ninety-four sediment samples were taken in the North Sea and coastal harbours in Belgium, in the following sampling areas:

- Voorhaven Zeebrugge (Inland harbour Zeebrugge);
- Centraal deel Nieuwe Buitenhaven (CDNB) Zeebrugge;
- Haven Nieuwpoort (Port of Nieuwpoort);
- Toegang Nieuwpoort (Access to the port of Nieuwpoort);
- Pas van het Zand;
- Scheur;
- Haven Blankenberge (Port of Blankenberge);
- Toegangsgeul Blankenberge (Access channel to the port of Blankenberge);
- Haven Oostende (Port of Oostende);
- Toegangsgeul Oostende (Access channel to port of Oostende);
- Coast of the North Sea;
- North Sea, Vlakte van de Raan.

The last two areas, North Sea coast and Vlakte van de Raan were added to the monitoring programme for scientific reasons. These two areas do not belong to the dredging areas and were not being sampled in previous sampling periods. Similar surveys were already conducted in 1989/1990 and in 2001. The purpose of the 2007 survey was to assess the quality of the sediment samples and to compare the results with those of previous monitoring programmes. All the samples were examined for their physico-chemical characteristics and for their concentration in organic and inorganic contaminants. 14 of these samples underwent a further ecotoxicological analysis. A partim description of the monitoring programme can be found in the synthesis report 2006-2008 (Lauwaert et al, 2008).

The sample locations are indicated in the maps Annexes at the end of this report.
4.2 Physico-chemical analysis of the samples

All 94 samples have been analysed on (wet bulk) density, dry matter, organic matter, distribution of particle size (fraction > 2001 µm, fraction < 2001 µm, fraction < 1000 µm, fraction < 500 µm, fraction < 250 µm, fraction < 63 µm, fraction < 45 µm, fraction < 16 µm, fraction < 2 µm), elements (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn), TPH, polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyl (PCB) and tributyltin (TBT).

The sediment quality criteria (SQC’s), namely the target and limit values for elements, Polycyclic Aromatic Hydrocarbons (PAH), TPH (Mineral Oil), Polychlorinated Biphenyl (PCB) and Tributyltin (TBT) are given in Table 4.1.

Table 4.1 summary of the sediment quality criteria (SQC’s) issued by MUMM

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<td>mg/kg</td>
<td>70</td>
<td>280</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>mg/kg</td>
<td>70</td>
<td>350</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>mg/kg</td>
<td>160</td>
<td>500</td>
</tr>
<tr>
<td>Polycyclic Aromatic Hydrocarbons (PAH)</td>
<td>µg/gOC</td>
<td>70</td>
<td>180</td>
</tr>
<tr>
<td>TPH (Mineral Oil)</td>
<td>mg/gOC</td>
<td>14</td>
<td>36</td>
</tr>
<tr>
<td>Polychlorinated Biphenyl (PCB)</td>
<td>µg/gOC</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Tributyltin (TBT)</td>
<td>µg/kg</td>
<td>3</td>
<td>7</td>
</tr>
</tbody>
</table>

If the analytical results exceed the limit value set for three of the criteria at the same time, the dredged materials cannot be dumped back at sea. If the result lies between the target value and the limit value, the number of samples has to be increased by five and new analyses have to be carried out. If the new results confirm the previous ones, then bioassays prescribed at international level have to be conducted. Negative results from these bioassays may lead to a ban on dumping of dredged materials from these delimited areas at sea.

Table 4.2 gives a summary of the test results.
<table>
<thead>
<tr>
<th>Elements</th>
<th>Voorhaven Zeebrugge (1 to 18)</th>
<th>CDN8 Zeebrugge (20 to 26)</th>
<th>Pas van het Zand (30 to 35)</th>
<th>Scheur (36 to 45)</th>
<th>Port Blankenberge (50 to 57)</th>
<th>Navigation channel Blankenberge (58)</th>
<th>Port Nieuwpoort (60 to 66, 69)</th>
<th>Navigation channel Nieuwpoort (67, 68)</th>
<th>Haven Oostende (70 to 86)</th>
<th>Navigation channel Oostende (87 to 94)</th>
<th>Coast of the North Sea (TS1 to TS4, TS9, TS12, WO2, WO3)</th>
<th>North Sea, Vlakte van de Raan (WO4, VDR1, VDR3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$V_{\text{Sarg}} &lt; V_{\text{Conc}} &lt; V_{\text{Lim}}$</td>
<td>$V_{\text{Conc}} &lt; V_{\text{Lim}}$</td>
<td>$V_{\text{Sarg}} &lt; V_{\text{Conc}} &lt; V_{\text{Lim}}$</td>
<td>$V_{\text{Sarg}} &lt; V_{\text{Conc}} &lt; V_{\text{Lim}}$</td>
<td>$V_{\text{Sarg}} &lt; V_{\text{Conc}} &lt; V_{\text{Lim}}$</td>
<td>$V_{\text{Sarg}} &lt; V_{\text{Conc}} &lt; V_{\text{Lim}}$</td>
<td>$V_{\text{Sarg}} &lt; V_{\text{Conc}} &lt; V_{\text{Lim}}$</td>
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<td>$V_{\text{Sarg}} &lt; V_{\text{Conc}} &lt; V_{\text{Lim}}$</td>
<td>$V_{\text{Sarg}} &lt; V_{\text{Conc}} &lt; V_{\text{Lim}}$</td>
<td>$V_{\text{Sarg}} &lt; V_{\text{Conc}} &lt; V_{\text{Lim}}$</td>
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<tr>
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<td>$V_{\text{Conc}} \geq V_{\text{Lim}}$</td>
<td>$V_{\text{Conc}} \geq V_{\text{Lim}}$</td>
<td>$V_{\text{Conc}} \geq V_{\text{Lim}}$</td>
<td>$V_{\text{Conc}} \geq V_{\text{Lim}}$</td>
<td>$V_{\text{Conc}} \geq V_{\text{Lim}}$</td>
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<td>-</td>
<td>26 ($^9$)</td>
<td>-</td>
<td>31-34-35</td>
<td>-</td>
<td>50 to 56 ($^{10}$)</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>58 ($^1$)</td>
<td>-</td>
<td></td>
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<td></td>
<td></td>
<td>63 ($^3$)</td>
<td>-</td>
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<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>79-82 ($^{VI}$)</td>
<td>83</td>
<td>82 ($^X$)</td>
<td>82 ($^3$)</td>
<td>77 ($^3$)</td>
<td>71-82-83 ($^{XI}$)</td>
<td>-</td>
<td>-</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>93 ($^1$)</td>
<td>-</td>
<td></td>
<td>-</td>
<td></td>
<td>-</td>
<td>-</td>
<td>WO2 ($^{XXX}$)</td>
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</tr>
</tbody>
</table>

Table 4.2: Test results
Legend

Legend

\(V_{\text{lim}}\): Limit Value

\(V_{\text{conc}}\): concentration

\(V_{\text{lim}}\): Target Value

\(V_{\text{lim}}\): Limit Value

\(V_{\text{conc}}\): concentration

Remarks I to XII:

(I): the highest concentrations for Tributyltin (TBT) were found in sample 1 (30.9 µg/kg – 4.4 x \(V_{\text{lim}}\)), sample 3 (37.4 µg/kg – 5.3 x \(V_{\text{lim}}\)) and sample 15 (537 µg/kg – 77 x \(V_{\text{lim}}\));

(II): the concentration for PCB in sample 26 was 3.0 µg/gOC (1.5 x \(V_{\text{lim}}\));

(III): the concentrations for Tributyltin (TBT) in the samples 20 to 26 were nowhere higher than 12 µg/kg (max. 1.7 x \(V_{\text{lim}}\));

(IV): the concentration for Tributyltin (TBT) in the sample 33 was 12.9 µg/kg (1.8 x \(V_{\text{lim}}\));

(V): the concentration for Tributyltin (TBT) in sample 45 is 55.5 µg/kg (8 x \(V_{\text{lim}}\));

(VI): the highest concentrations for Tributyltin (TBT) were found in sample 50 (27.5 µg/kg – 3.9 x \(V_{\text{lim}}\)), sample 51 (28.1 µg/kg – 4 x \(V_{\text{lim}}\)) and sample 55 (28.4 µg/kg – 4.1 x \(V_{\text{lim}}\));

(VII): the total concentration for PAH (sum of 16 EPA PAH) in the sample 67 was 112 µg/gOC;

(VIII): the highest concentrations for elements were found for copper (240 mg/kg in sample 83 – 2.4 x \(V_{\text{lim}}\)) and zinc (1500 mg/kg in sample 83 – 3 x \(V_{\text{lim}}\));

(IX): the concentration for TPH in sample 82 is 65 mg/gOC (1.5 x \(V_{\text{lim}}\));

(X): the concentration for PCB in sample 82 is 2.03 µg/gOC;

(XI): the concentrations for Tributyltin (TBT) in sample 82 (4284.9 µg/kg – 612 x \(V_{\text{lim}}\)) and sample 83 (2595.6 µg/kg – 371 x \(V_{\text{lim}}\)) were remarkably high;

(XII): the concentration for Tributyltin (TBT) in sample WO2 is 8.9 µg/kg (1.3 x \(V_{\text{lim}}\));

Remarks 1 to 3:

(1): The (recalculated) detection limit for these samples is not exceeded while the absolute value of the detection limit for these samples is higher than the target value for TPH (14 mg/gOC). Because of this discrepancy, it is not possible to interpret and discuss the analysis results of these samples.

(2): The (recalculated) detection limit for these samples is not exceeded while the absolute value of the detection limit for these samples is higher than the limit value for TPH (36 mg/gOC). Because of this discrepancy, it is not possible to interpret and discuss the analysis results of these samples.

(3): The detection limit for these samples is not exceeded while the absolute value of the detection limit for these samples is higher than the target value for TBT (3 µg/kg). Because of this discrepancy, it is not possible to interpret and discuss the analysis results of these samples.

TBT is the most limiting analysed parameter to describe the quality of the sediments from the North Sea and coastal harbours in Belgium. In the harbour sections of Zeebrugge and Blankenberge, approx. 94 % of the samples exceeded the limit value for TBT. In the harbour section of Nieuwpoort and Oostende, approx. 12 % of the samples exceed the limit value for TBT while in the Pas van het Zand, Scheur Oost and Scheur West (navigation channels) 12.5 % of the samples exceeded the limit value for TBT.

For the reference samples (TS1-2-3-4-9-12, WO2-3-4, VDR1-3/ no dredging zones) some 10 % of the samples exceeded the limit value for TBT. The last value is mainly due to sample WO3.

The results of the 2007 campaign have been compared to those of the 1990 and 2001 campaigns. To compare the test results of the monitoring programme of 2001 with these of 2007, a student t-test was used. Because a comparison of the individual results for a certain sampling spot is not relevant, a comparison of the average values was performed for each sampling area. To investigate whether the mean values for the monitoring programmes of 2001 and 2007 are significantly (level 5 %) different for a certain analysis parameter and for a certain sampling area, the probability of finding these observed mean values under the assumption (H₀ hypothesis) that the population means are equal, is calculated. To calculate these probabilities the student t-test is used. Since the variation may have changed over time, the student t-test for hetero-
scedastic data is used. A 2-sided test is used because the pollution level of the sediments may have increased or decreased.

For the monitoring programme of 1990 the data of the individual analysis results are not available and a student t-test was not performed, instead a comparison was made between the average values.

4.3 Comparison 2001-2007

In Table 4.3 the results of the student t-test are summarized for each sampling area. For each parameter it is mentioned whether the average analytical results (mean values) have decreased, increased or have been stable over the monitoring programmes of 2001 and 2007 on significant level $\alpha = 5\%$. The symbol ‘–’ is used if the mean values have been stable.

Table 4.3 comparison of the 2001 & 2007 monitoring programme, based on the student t-test results.

<table>
<thead>
<tr>
<th>Elements</th>
<th>PAH</th>
<th>TPH</th>
<th>PCB (*)</th>
<th>TBT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voorhaven Zeebrugge</td>
<td></td>
<td>![increase]</td>
<td>![decrease]</td>
<td>–</td>
</tr>
<tr>
<td>CDNB Zeebrugge</td>
<td>![increase]</td>
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<td>![decrease]</td>
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</tr>
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<td>Pas van het Zand</td>
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<tr>
<td>Scheur</td>
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<td>![decrease]</td>
<td>![decrease]</td>
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</tr>
<tr>
<td>Haven Blankenberge</td>
<td>![increase]</td>
<td>![decrease]</td>
<td>![decrease]</td>
<td>![decrease]</td>
</tr>
<tr>
<td>Haven Nieuwpoort</td>
<td>![increase]</td>
<td>![decrease]</td>
<td>![decrease]</td>
<td>![decrease]</td>
</tr>
<tr>
<td>Toegang Nieuwpoort</td>
<td>![increase]</td>
<td>![decrease]</td>
<td>![decrease]</td>
<td>![decrease]</td>
</tr>
<tr>
<td>Haven Oostende</td>
<td>![increase]</td>
<td>![decrease]</td>
<td>![decrease]</td>
<td>![decrease]</td>
</tr>
<tr>
<td>Toegangsgeul Oostende</td>
<td>![increase]</td>
<td>![decrease]</td>
<td>![decrease]</td>
<td>![decrease]</td>
</tr>
</tbody>
</table>

Legend
– : the mean values have been stable over the monitoring programmes 2001 and 2007.

![increase]: Increase, ![decrease]: Decrease

(*): In 2001 the detection limit for PCB was remarkably higher than in 2007. In 2001 most results were equal to their detection limit. As a result, the evolution trend cannot be documented.

(**): The mean value for TBT in 2001 is equal to the detection limit of ‘< 5 $\mu$g/kg’. The absolute value of the detection limit (‘5 $\mu$g/kg’) is higher than the target value for TBT. There is surely no increase over time. Whether the mean values have decreased or have been stable over time cannot be concluded.

The mean values for chromium in 2001 and 2007 exceed the target values in the areas ‘Voorhaven Zeebrugge’ and ‘CDNB Zeebrugge’. In the area ‘Haven Blankenberge’ the mean value for chromium exceeds the target value in 2001. In the area ‘Haven Oostende’ the mean values exceed the target value for copper in 2001 and in 2007 and for chromium in 2001. For no other elements the mean values exceed the target values. In the area ‘Voorhaven Zeebrugge’ the mean values for chromium have decreased over time, in the area ‘Haven Oostende’ they have increased and in the areas ‘CDNB Zeebrugge’ and ‘Haven Blankenberge’ they have been stable on significance level $\alpha = 5\%$.

The mean values for copper have been stable on significance level $\alpha = 5\%$ in the area ‘Haven Oostende’.

The mean values for PAH exceed the target values in the area ‘Toegang Nieuwpoort’ in 2007 and in the area ‘Haven Oostende’ in 2001.

In the area ‘Haven Oostende’ the mean values have decreased over time. In the area ‘Toegang Nieuwpoort’ they have been stable on significance level $\alpha = 5\%$. 

82
The mean value for TPH exceeds the target value in the area ‘Toegang Nieuwpoort’ in 2007. In this area the mean values did not change over time on significance level $\alpha = 5\%$.

The evolution of PCB over time cannot be well documented because of the detection limit for PCB was remarkably higher for the monitoring programme of 2001 compared to 2007.

In none of the sampling areas the values for TBT have increased over time. In most of the areas the values for TBT have decreased.

Except for the area ‘Toegang Haven Nieuwpoort’, for all the other areas the mean values for TBT exceeded the limit value in 2001. In the area ‘Toegang Haven Nieuwpoort’ the mean value for TBT exceeded the target value in 2001.

For the area ‘Pas van het zand’ the decrease over time means a decrease below the limit value in 2007.

For the areas ‘Nieuwpoort Haven’ and ‘Toegangsgeul Oostende’ the decrease over time means a decrease below the target value in 2007.

For the area ‘Toegang Nieuwpoort’ the evolution trend cannot be documented because the detection limit for TBT was remarkably higher in 2001 than in 2007.

For the other areas the decrease over time means no decrease below the limit value in 2007.
4.3.1 Comparison 1990-2001-2007

- **Arsenic**
- **Cadmium**
- **Chromium**
- **Copper**
- **Lead**
- **Mercury**
In the area ‘Voorhaven Zeebrugge’ the mean values for chromium exceeded the target values in 2001 and 2007. In 1990 the mean values for cadmium, copper, mercury, lead and zinc exceeded the target values (not for chromium). For all elements, except for chromium, a global decrease is noticed over time. For chromium an increasing trend (from 1990 to 2001) is followed by a decreasing trend on significance level $\alpha = 5\%$ (from 2001 to 2007).

In the area ‘CDNB Zeebrugge’ the mean values for chromium exceeded the target values slightly in 2001 and 2007. In 1990 the mean values for cadmium exceeded the target value lightly (not for chromium). For cadmium there seems a global decreasing trend over time. For chromium there seems an increasing trend from 1990 to 2001. The mean values for chromium have been stable from 2001 to 2007 on significance level $\alpha = 5\%$.

In the area ‘Pas van het Zand’ the mean value for mercury exceeded slightly the target value in 1990. There seems a decreasing trend over time for mercury.
In the area ‘Haven Blankenberge’ the mean value exceeded the target value slightly for mercury in 1990 and for chromium in 2001. There seems a decreasing trend over time for mercury. For chromium there seems an increase from 1990 to 2001. The mean values for chromium have been stable from 2001 to 2007 on significance level $\alpha = 5\%$.

In the area ‘Haven Oostende’ the mean values for copper exceeded the target value in the 3 monitoring programmes. Only in 2007 the mean value for chromium exceeded the target value. The mean values for chromium have increased over time. It seems that the mean values for copper have been stable.

In the other areas ‘Scheur, Haven Nieuwpoort, Toegang Nieuwpoort, Toegangsgeul Oostende’ the mean values of any of the elements did not exceed the target or limit values.

4.3.2 Recommendation for the future

Occasionally, a high variation in concentrations was found between sampling spots that are located close together (e.g. for TBT in the areas “Pas van het Zand” and “Scheur” and for PAH in the area “Toegang haven Nieuwpoort”). In order to reduce the spatial variation between test results of nearby samples, the sampling method could be adapted in the future.

4.3.3 Expanded monitoring 2007, executed in 2008

In the 2007 survey, only one sample was taken for each of the sampling locations. This did not always allow for a clear interpretation of the results. Therefore, the recommendation was made to increase the number of samples per sampling location. Combining these in order to get one composite sample, allows for more representative quality analyses results. A small scale study (on 13 sampling locations, see table and map at Figure 4.2) was set up in order to investigate alternative sampling techniques as well as to confirm/reconfirm certain analysis results.

<table>
<thead>
<tr>
<th>Description of the sampling areas</th>
<th>Sample numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haven Zeebrugge</td>
<td>Samples 1, 3, 15, 26</td>
</tr>
<tr>
<td>Visartsluis</td>
<td>Samples Z1, Z2, Z3</td>
</tr>
<tr>
<td>Toegangsgeul Blankenberge</td>
<td>Samples 51, 56</td>
</tr>
<tr>
<td>Haven Oostende</td>
<td>Samples 83, V1, V2, 71</td>
</tr>
</tbody>
</table>
The 2008 study included three samples per sampling location, taken in a grid. These were combined to one composite sample for analysis. In this way, the analysis results are likely to be more representative.

In general, the results of the analysis confirm the previous results of 2007. In the majority of the samples, no significant differences were found. An exception is sample 15 (Zeebrugge Harbour), where TBT in the present composite sample is remarkably lower than in the previous campaign. Given the more intensive sampling, the current results are considered to be more representative.

4.4 Ecotoxicological analysis of the sediments

The possible ecotoxicity of fourteen sediment samples (see location code in Table 4.4 and maps at Annexes) from the 94 taken from different Belgian coastal ports and North sea locations has been investigated, using ecotoxicological tests with the bacterium *Vibrio fischeri* (Microtox test), the marine rotifer *Brachionus plicatilis* (Rotoxkit M.), the lugworm *Arenicola marina*, the mud shrimp *Corophium volutator* and the Japanese oyster *Crassostrea gigas*. A comparison was also made between the ecotoxicological and physicochemical results from 2001 and this research (2007), and wherever possible also with the physicochemical research from 1990.

Both in 2001 and 2007, negative impact was shown in several samples with several organisms.

This is remarkable, since the results of the chemical analyses showed that the samples (except for TBT) had not been polluted strongly and that (except a marked local increase or decrease in the TBT content) no large differences in the pollution degree could be found between 2001 and 2007.
For this reason in the analysis of the data from both years clear attention was given to the possible influence of background contaminants such as sulphide and ammonium and the influence of the granulometry of the sample.

These factors proved to be important. When interpreting the results, negative impact on organisms caused by the grain size distribution, have not been assessed as toxic, because the grain size is not considered a toxicant. Impact which has been probably caused by raised ammonium and/or sulphide content has been, however, assessed as a toxic impact, but this impact cannot be considered as an indication for the presence of anthropogenic contaminants. In the final judgement the impact caused by the exceeding of the background values has not been considered.

Table 4.4 gives the comparison between the results of the ecotoxicological tests of 2001 and 2007.

Table 4.4 qualitative assessment of the ecotoxicological tests in 2001/2007

<table>
<thead>
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</tr>
<tr>
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<td>+</td>
<td>–</td>
<td>–</td>
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</tr>
</tbody>
</table>

– = no toxic effect ± = moderate toxic effect + = serious toxic effect. Bio-assays where the negative effect probably (most likely) is caused by an exceedance of the background values are shown between brackets.

Qualitative judgement of samples where an exceedance of the background values are given two evaluations: between brackets the effect, including the background values is shown, the second value is based on the effects that are not influenced by the background values.

Based on the final judgement it appears that in both 2001 and 2007, two samples caused toxic impacts. For the 2001 samples, it is sample 20 from Zeebrugge CDNB (on Corophium volutator) and sample 61 from Nieuwpoort yacht-basin (Rotoxkit M.). For the 2007 campaign, sample WO3 at Oostduinkerke Westdiep (Microtox) and WO4 at the Bol van Knokke (oyster larvae). Only in the case of the sample at the Bol van Knokke the impact was toxic classify as seriously. The other three were labelled as moderately toxic. The toxicity in the sample from Zeebrugge CDNB can be very probable attributed to ammonium—in spite of the fact that no threshold values were exceeded.

For the sample from Nieuwpoort yacht-basin it was not possible to indicate with complete confidence which parameter was causing the toxicity. However, the toxicity seems
to have decreased in this sample, because in 2007 none of the bioassays showed a toxic impact, other than those caused by the background values.

The sediment composition of the samples WO3 and WO4, taken outside the harbour and added for scientific reasons, differed significantly from the remaining samples and is characterised by coarser grain sizes, very little silt content and a poor organic substance structure.

The toxic impact of these samples cannot be explained directly based on the chemical analysis, except from an overshooting for mercury in sample WO4. The sediment composition of these samples can however have contributed to a high bioavailability of contaminants. This can explain the toxicity of these sediments. A comparison of the toxicity with previous years could not be performed for these samples.
4.5 Qualitative comparison TBT Analysis

TBT analysis is a difficult exercise, so it was decided that some of the samples which were analysed by the ecotoxicological laboratory (1-13) and some samples which were taken directly from the dredging vessels (hopper) (14-32), were also sent to the MUMM laboratory in Ostend. The results of this comparison exercise can be found below.

Table 4.5. TBT analyses: comparison study between two labs (in µg/kg dry substance).

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Location</th>
<th>sampling date</th>
<th>Unit</th>
<th>in situ/ hopper</th>
<th>Results from Lab Eurofins</th>
<th>Results TBT Lab MUMM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 (Zeebrugge - voorhaven Britanniadok)</td>
<td>10/8/2008</td>
<td>µg/kg ds</td>
<td>in situ</td>
<td>16.3</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>3 (Zeebrugge - voorhaven Britanniadok)</td>
<td>10/8/2008</td>
<td>µg/kg ds</td>
<td>in situ</td>
<td>14.2</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>15 (Zeebrugge - Militair tijdok 2)</td>
<td>10/8/2008</td>
<td>µg/kg ds</td>
<td>in situ</td>
<td>&lt; 1.3</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>26 (Zeebrugge - CDNB Wielingendok)</td>
<td>10/8/2008</td>
<td>µg/kg ds</td>
<td>in situ</td>
<td>13.4</td>
<td>4.6</td>
</tr>
<tr>
<td>5</td>
<td>Z1 (Zeebrugge - Visartsluis)</td>
<td>10/8/2008</td>
<td>µg/kg ds</td>
<td>in situ</td>
<td>147</td>
<td>83</td>
</tr>
<tr>
<td>6</td>
<td>Z2 (Zeebrugge - Visartsluis)</td>
<td>10/8/2008</td>
<td>µg/kg ds</td>
<td>in situ</td>
<td>224</td>
<td>140</td>
</tr>
<tr>
<td>7</td>
<td>Z3 (Zeebrugge - Visartsluis)</td>
<td>10/8/2008</td>
<td>µg/kg ds</td>
<td>in situ</td>
<td>35.8</td>
<td>32</td>
</tr>
<tr>
<td>8</td>
<td>Z6 (Blankenberge havengeul)</td>
<td>10/8/2008</td>
<td>µg/kg ds</td>
<td>in situ</td>
<td>&lt; 1.1</td>
<td>5.7</td>
</tr>
<tr>
<td>9</td>
<td>51 (Blankenberge spuikom)</td>
<td>10/8/2008</td>
<td>µg/kg ds</td>
<td>in situ</td>
<td>20.1</td>
<td>22</td>
</tr>
<tr>
<td>10</td>
<td>83 (Oostende - Visserijdok)</td>
<td>10/8/2008</td>
<td>µg/kg ds</td>
<td>in situ</td>
<td>3250</td>
<td>2900</td>
</tr>
<tr>
<td>11</td>
<td>V1 (Oostende - Visserijdok)</td>
<td>10/8/2008</td>
<td>µg/kg ds</td>
<td>in situ</td>
<td>1630</td>
<td>1800</td>
</tr>
<tr>
<td>12</td>
<td>V2 (Oostende - Visserijdok)</td>
<td>10/8/2008</td>
<td>µg/kg ds</td>
<td>in situ</td>
<td>2230</td>
<td>2000</td>
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<tr>
<td>13</td>
<td>71 (voorhaven kanaal Brugge-Oostende)</td>
<td>10/8/2008</td>
<td>µg/kg ds</td>
<td>in situ</td>
<td>35</td>
<td>11</td>
</tr>
</tbody>
</table>

In hopper samples simultaneously analysed by L.E. and MUMM

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Location</th>
<th>sampling date</th>
<th>Unit</th>
<th>in situ/ hopper</th>
<th>Results from Lab Eurofins</th>
<th>Results TBT Lab MUMM</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>CNCB (04-09-2008)</td>
<td>9/4/2008</td>
<td>µg/kg ds</td>
<td>in hopper</td>
<td>&lt; 1.16</td>
<td>6.5</td>
</tr>
<tr>
<td>15</td>
<td>Toegang Zeesluis (04-09-2008)</td>
<td>9/4/2008</td>
<td>µg/kg ds</td>
<td>in hopper</td>
<td>&lt; 1.0</td>
<td>5.1</td>
</tr>
<tr>
<td>16</td>
<td>A-2 DOK (04-09-2008)</td>
<td>9/4/2008</td>
<td>µg/kg ds</td>
<td>in hopper</td>
<td>&lt; 1.02</td>
<td>3.9</td>
</tr>
<tr>
<td>17</td>
<td>All-DOK (04-09-2008)</td>
<td>9/4/2008</td>
<td>µg/kg ds</td>
<td>in hopper</td>
<td>&lt; 1.06</td>
<td>4.2</td>
</tr>
<tr>
<td>18</td>
<td>TGZS N+Z R65 (05-09-2008)</td>
<td>9/5/2008</td>
<td>µg/kg ds</td>
<td>in hopper</td>
<td>&lt; 1.13</td>
<td>6.7</td>
</tr>
<tr>
<td>19</td>
<td>CNCB R66 (05-09-2008)</td>
<td>9/5/2008</td>
<td>µg/kg ds</td>
<td>in hopper</td>
<td>&lt; 1.14</td>
<td>9.0</td>
</tr>
<tr>
<td>20</td>
<td>ZP1 Reis7 (08-09-2008)</td>
<td>9/8/2008</td>
<td>µg/kg ds</td>
<td>in hopper</td>
<td>&lt; 1.23</td>
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</tr>
<tr>
<td>21</td>
<td>CNCB Reis11 (08-09-2008)</td>
<td>9/8/2008</td>
<td>µg/kg ds</td>
<td>in hopper</td>
<td>&lt; 1.35</td>
<td>6.7</td>
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<tr>
<td>22</td>
<td>CNCB Reis11 (08-09-2008)</td>
<td>9/8/2008</td>
<td>µg/kg ds</td>
<td>in hopper</td>
<td>&lt; 1.32</td>
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<td>23</td>
<td>ZP1 Reis24 (09-09-2008)</td>
<td>9/9/2008</td>
<td>µg/kg ds</td>
<td>in hopper</td>
<td>&lt; 1.16</td>
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<tr>
<td>24</td>
<td>AVH 19-02-09 CDMB</td>
<td>2/19/2009</td>
<td>µg/kg ds</td>
<td>in hopper</td>
<td>8.6</td>
<td>4.2</td>
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<tr>
<td>25</td>
<td>AVH 19-02-09 NOORD</td>
<td>2/19/2009</td>
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<td>in hopper</td>
<td>5.5</td>
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<tr>
<td>26</td>
<td>AVH 19-02-09 ZUID</td>
<td>2/19/2009</td>
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<td>in hopper</td>
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<tr>
<td>27</td>
<td>AVH 20-02-09</td>
<td>2/20/2009</td>
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<td>in hopper</td>
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<td>6.4</td>
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<tr>
<td>28</td>
<td>A2 DOK 19-02-09 Mellina Reisnr46</td>
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<td>29</td>
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<td>µg/kg ds</td>
<td>in hopper</td>
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<td>in hopper</td>
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<td>µg/kg ds</td>
<td>in hopper</td>
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<td>19</td>
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<tr>
<td>32</td>
<td>A2DOK 19-12-09 Mellina Reisnr58</td>
<td>2/19/2009</td>
<td>µg/kg ds</td>
<td>in hopper</td>
<td>9.6</td>
<td>9.6</td>
</tr>
</tbody>
</table>

It is clear that the results are mostly in the same order of magnitude, with some higher values measured by MUMM on under limit detection samples for Lab Eurofins (3, 8, 14-19, 21, 23). In the future a more intense comparison exercise could be organised.
References


Van Mierlo C.-J. (1897). Quelques mots sur le régime de la côte devant Heyst. Ann Assoc Ingénieurs Gand XX.


**Abbreviations**

BCS: Belgian Continental Shelf

BPNS: Belgian Part of the North Sea

DW: Dry Weight

mab: meter above bed

MLLWS: Mean Lowest Low Water at Spring tide

MSL: Mean Sea Level

SPM: Suspended Particulate Matter

WW: Wet Weight
Annexes

- Overview map of sampling locations for physico-chemical and ecotoxicological analysis.
- Detail map of sampling points North Sea.
- Detail map of sampling Zeebrugge.
- Detail map of sampling Blankenberge en Nieuwpoort.
- Dredging and disposal intensity in 2007 for the Belgian coastal area.
- Dredging and disposal intensity in 2008 for the Belgian coastal area.
Sediment sample locations for physico-chemical and ecotoxicological analysis