# A NEW APPROACH FOR MANAGING THE MORPHOLOGY AND ECOLOGY OF A COASTAL PLAIN ESTUARY

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**ABSTRACT**

An expert team appointed by the Port of Antwerp proposed the idea of morphological dredging, aiming at steering the estuarine morphology. A pilot project was implemented, modifying the shape of a sandbar by disposing dredged material on the eroded tip of the Walsoorden sandbar. The new shape would help restoring the degraded ecology and morphology, but it also aims at modifying the flow on a crossing in the navigation channel, reducing the dredging effort if the self-dredging capacity of the flow could be increased on it.

A research programme about the feasibility of the idea was conducted in 2002 and 2003, combining several tools: desk studies on historical changes with maps, field measurements, physical scale model tests and numerical simulations. The expert team concluded in 2003 that none of the results denied the feasibility of the new disposal strategy, although final judgement would only be possible after the execution of an in situ disposal test.

During one month at the end of 2004, 500.000 m³ of sand was disposed with a diffuser in relatively shallow water at the seaward end of the sandbar. The experiment was well monitored with frequent multi-beam bathymetric surveys, LIDAR-flights, marked sediment tracing, in-situ sediment measurements and ecological monitoring. After one year, it was concluded that the test was a success from morphological viewpoint. Also the ecological monitoring did not reveal any significant negative changes in trends due to the disposal test.

In 2006 a new disposal test was executed, using the traditional technique with hopper dredgers. Due to practical limitations, the disposal (again 500.000 m³) was spread over a 3 months period. The new experiment was again thoroughly monitored for morphology as well as for ecology. Up to now, the morphological results of the second test are satisfying. The ecological results will become available during the first half of 2007, with the preliminary results not showing any negative impact.

*Keywords* : morphological management, disposal strategy, Western Scheldt, eco-morphology

## INTRODUCTION

The morphology of an estuary is continually changing, adjusting to the ever-changing forcing processes, natural and man-made, so that no estuary may be considered as stable, so that habitats and the ecological functioning of the estuary will continually evolve, even in absence of human intervention. Understanding of the functioning of the estuary is required for predicting the effect of human activities, such as dredging and disposal, but also the construction of flow regulating structures and dikes. A holistic management plan is also needed, harmonizing the too often conflicting interests of the various stakeholders.

This paper focuses on the case of the Scheldt estuary, where a morphological management is needed to conciliate nature preservation, safety against flooding and port accessibility. The Scheldt is the aorta to the port of Antwerp, while it is one of the few remaining European estuaries covering the entire gradient from fresh to salt water tidal areas.

## 1. OVERVIEW OF HISTORICAL EVOLUTIONS

At the end of the Pleistocene, the last ice age, rivers in North-West Europe discharged in the Atlantic Ocean in the vicinity of the Doggersbank, far away from the present shores. With the warming up of the climate, the sea level rose very quickly over more than 100 meters from 20 Kyr BP to about 7 Kyr BP, then slower to become (comparatively) rather stable over past two millenaries. The past rising sea level reshaped strongly the coastal areas and estuaries at the end of the Holocene. Many of these morphological changes are still ongoing.

In front of the actual Belgian, Dutch and German coast an almost continuous chain of sandy bars and islands existed was formed (Figure 1), creating an inner sea was formed, a kind of an extensive lagoon of which remains only the Wadden Sea. The sand barrier between lagoon and open sea was regularly breached during storms, scouring large channels deep into the inner sea. River sediments filled those parts of the lagoon receiving streams with large sand discharges, like the Rhine. In other parts receiving little and more silty sediment loads, like from the Scheldt river, tidal action penetrated progressively, developing further the sea branches. Import of marine sediments by the tidal currents formed large shoals in the lagoon. Around 1000 A.D., Zeeland had become a patchwork of islands, surrounded by an intricate network of tidal channels. At that time, the river Scheldt discharged in the lagoon near Bergen op Zoom and both the Honte (present Western Scheldt) and the Eastern Scheldt were conducting the Scheldt river water to the North Sea. Till the 11th century, morphological evolutions were significant but fully natural, with almost no human impact.

First signs of human impact on the estuary's environment become visible in the 11th century: locals reclaimed land that had silted up high enough and started to protect it against flooding. However, inundations due to levee breaching during storm events returned repeatedly portions of land to the river. From the 16th century on, the polder techniques had become more sophisticated and larger areas were permanently reclaimed. Land reclamation continued till the 1960's. Hydraulic works and storms further contributed to reshape the area. In 1867 and 1871, the two remaining links (Kreekrak and Sloe) between the Honte (Western Scheldt) and the Eastern Scheldt were cut-off, modifying drastically the tidal channels network. A catastrophic storm with extensive inundation, in 1953, made the Netherlands decide about executing an extensive flood protection plan "Delta". From historical data can be concluded that these human impacts such as closure of secondary channels and poldering have strongly influenced the tidal regime of the Western Scheldt, contributing to enlarge the main navigation channel. Also sand mining, starting at the end of the 19th century, affects the estuary. Since 1958, about 1 to 2 million cubic meters of sand was mined per year.

At the end of the 19th century, dredging activities (Figure 2) were required to improve the accessibility of the port of Antwerp. Until the 1920's, these activities were concentrated on the Belgian territory (2 $Mm^3$/year). From 1920 till 1960 the quantities on Belgian and Dutch territory were comparable (2 + 2 Mm³/year). The first large deepening campaign happened in the early 1970's, the main part of dredging works on Dutch territory (3 + 10 Mm³/year). Nonetheless, the increased dredging in the Dutch part did not result in significant changes of the trend in morphology or tidal action. During the late 1990's, a second dredging campaign for improving the navigation conditions was conducted. The impact of the deepening by 4 feet is monitored (MOVE programme), but no significant negative impact was noticed yet.

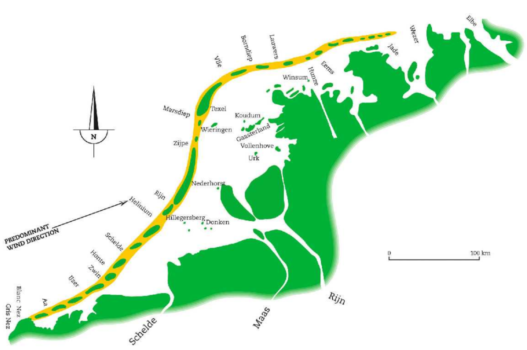


*Figure 1: Situation during the Roman times*

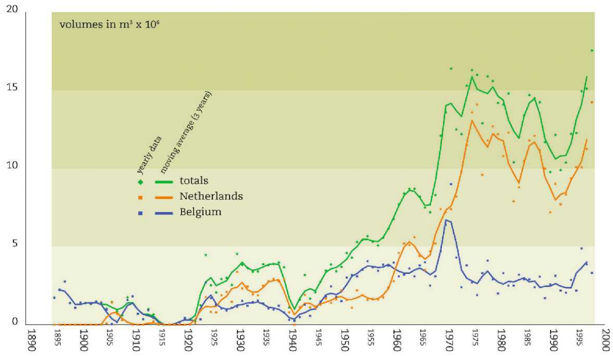


*Figure 2: Dredging activities in the Scheldt estuary since 1895*

## 2. MAINTAINING ACCESSIBILITY IN A MORPHOLOGICAL DYNAMIC ESTUARY

The morphological evolution of the estuary between 1800 and 2000 (Figure 3) is one of further shoal aggradation and enlargement of the main channels. The estuary is described as a multiple flood and ebb channel network. Historical maps reveal that the ebb or flood function of channels is not always obvious and sometimes even unclear. Ebb channels may turn into flood channels, and vice versa (see middle part of the estuary on Figure 4). The reduced mobility of the channels and shoals is mainly due to the hard bordering of the estuary (levees, bank protections, groynes, jetties and harbours); sandbars are rising too high, channels deepen, shallow water areas diminish.

Till 1970, maintenance dredging aimed to keeping depths on crossings in the navigation route, formed by main ebb channels. Traditionally, sediments were disposed in flood channels with the idea that it would take a long time before returning to the main ebb channel. During a first deepening in 1970, dredged sediments were still disposed in flood channels. Disposal sites were decided in common by the Dutch and the Belgium administrations on the basis of the assessment of the ongoing morphological changes. The procedures were adjusted due to the increasing environmental concerns and with institutional changes in Belgium, Flanders becoming responsible for public works and infrastructure. In 1995, Flanders and the Netherlands reached an agreement to deepen further the Western Scheldt shipping route. Works were executed in 1997 and 1998. However, the amount of sediment disposed in the eastern part of the Western Scheldt was reduced when some flood channels aggraded, supposedly because too much sediment had been disposed there. This siltation could eventually jeopardise the existence of the multi-channel system in that reach. Therefore, from 1997 on, more material was moved to disposal sites in the western reach of the estuary.

In 1999, the Dutch and Flemish governments decided to set up a Long-Term Vision (LTV) project with 3 objectives: to ensure maximum safety against flooding, optimal accessibility of the ports within the estuary and optimal nature development. These 3 subjects are all related to the morphology of the estuary. Directly concerned by these issues, the autonomous Port of Antwerp, independent from the Flemish administration, requested a group of experts (called Port of Antwerp Expert Team, or "PAET") to give an opinion about the prospects for a further deepening and widening of the navigation route, mainly needed for the larger container ships.

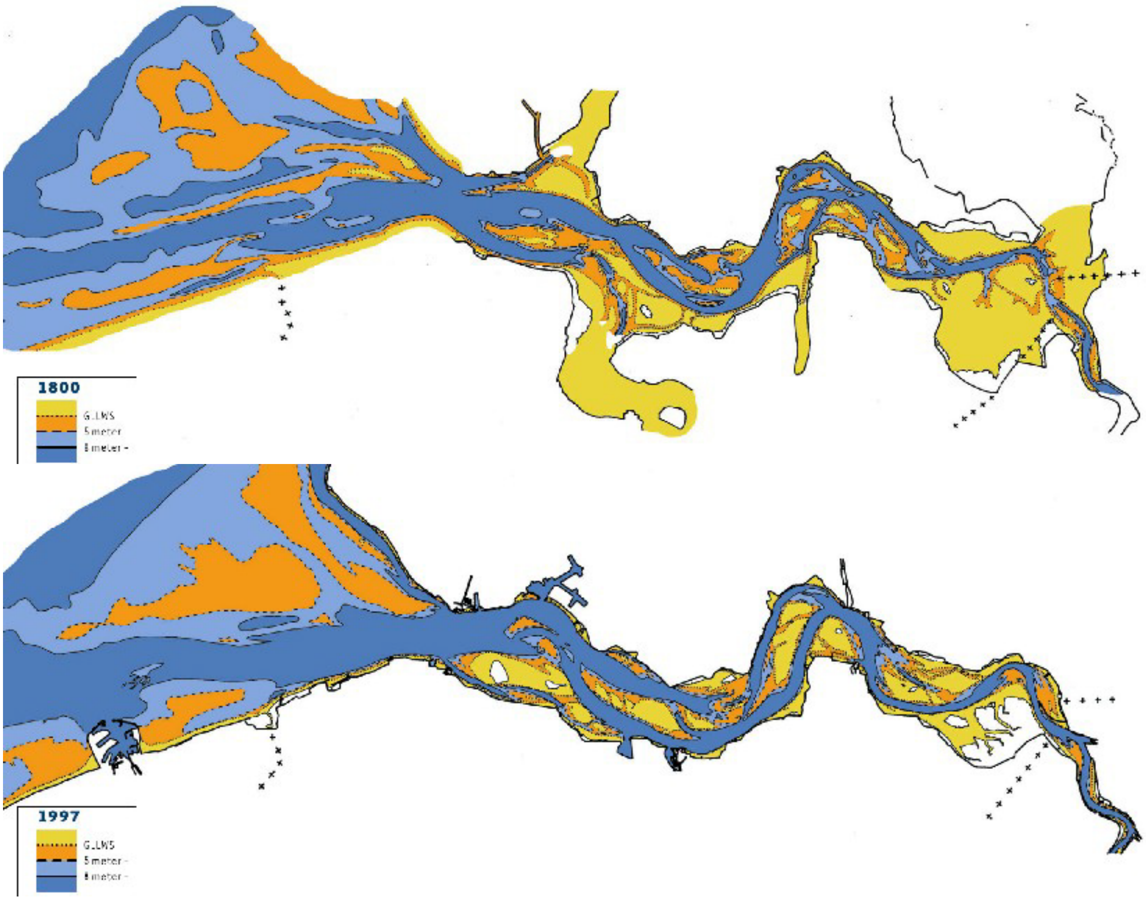


*Figure 3: Morphological evolution of the Western Scheldt estuary 1800 – 1997*

One of the critical issues considered in LTV was where to dispose the large volumes needed for such an enlargement? Dutch researchers had claimed that flood channels would disappear if too large quantities of sediment were to be disposed there. Their conclusions were based on some assumptions and simulations with modelling tools, of which one is based on the so-called "cell-theory" [Wang et al., 1995 – Winterwerp et al., 2001]. A "cell" is composed of an ebb channel and a flood channel and the enclosed inter-tidal flats. According to this theory, sediment circulates in "cells", with a net landward movement in the flood channels and a net seaward one in the ebb channels. The Port of Antwerp experts consider this schematisation as too simplistic. Based on their analysis of past morphological changes in general and of the (temporary?) decay of some flood channels, they stated that not (only) disposal of sediments was to be blamed, rather the always more stringent immobilisation of the main channels and shoals. To revert the reducing dynamic morphological behaviour of the estuary, the team proposed to steer the development of channels and shoals.

Recent studies show that the disposal of dredging materials has a much larger impact on the estuarine morphology than the deepening of the channels [ProSes, 2004]. New strategies for disposal are thus needed, although the Port of Antwerp expert team believes that dredging may also be beneficial for morphology, e.g., rectifying the shape of sandbars.

In 2002, the Dutch and Flemish governments signed a memorandum of understanding to implement together the Long-Term Vision programme. They set up jointly an organisation called ProSes (Project Direction for the Development Scheme of the Western Scheldt Estuary) funded by both regions and which main task was to establish the development scheme with the objectives to be reached in 2010.

## 3. MORPHOLOGICAL MANAGEMENT OF THE WESTERN SCHELDT

### 3.1. Morphological dredging

In the year 2000, the Port of Antwerp experts proposed to LTV “morphological dredging” as an alternative to the present dredging strategies, based on principles developed for the maintenance and capital dredging in the maritime reach of the Congo river, redistributing the sediment transport and using dredging and disposal to change the plan form of the river.

Disposal is a way to redistribute the sediment in the Western Scheldt, so as to feed, as an example, areas eroding too much, not only in the flood channels, also on some parts of shoals. The Port of Antwerp expert team worked out the proposal for restoring the tip of the Walsoorden sandbar that erodes since several decades. Several millions of cubic meters of sediment could be stored at that place (Figure 5 – white hatching). The technique could be applied in other places along the estuary. One advantage of the proposal is that the additional volumes produced by the capital dredging required for a further improvement of the navigation route could be kept within the estuary instead of exporting it out of the estuary, into the sea. Nobody knows today what would result for the Western Scheldt from such an export in terms of tidal propagation and environmental impact. The estuary is said to have very little sediment exchange with the sea and the quantity of sediment supplied by the river is rather small, limited to very fine material, mainly silt and clay.

### 3.2. Technology for morphological dredging

The dredging companies contacted for advice about the disposal of material in controlled way close to the riverbed have developed a system by which the sediment is disposed quietly with a diffuser in shallow water (Figure 5). This technique has already successfully been applied in coastal areas [Goossens & Bosschem, 2002].

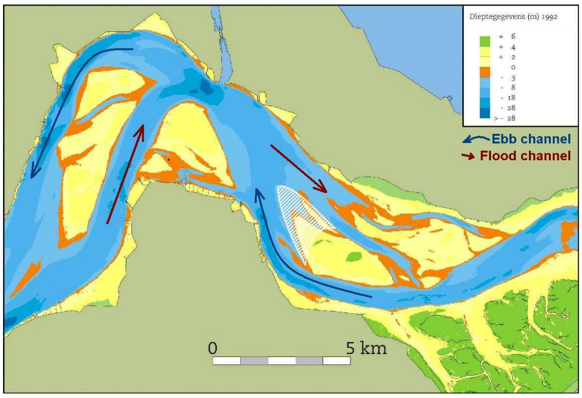


*Figure 4: Walsoorden area*

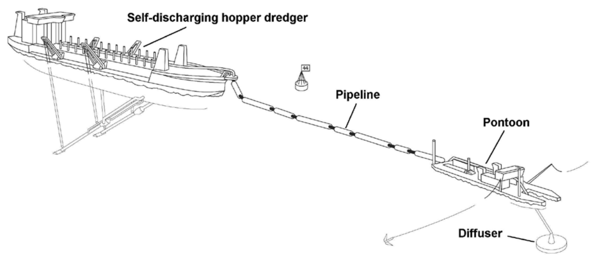


*Figure 5: Schematisation of disposal technique*

### 3.3. Potential benefits for the environment

A careful choice of disposal sites, based on good field data and possibly completed with modelling, may produce a selective spatial dispersion of the sediments along the sandbar. Coarse particle fractions will preferentially move in the deeper areas, the finer moving towards the shallows, possibly up to the top of the bar. During the process, the change in morphology by aggrading up some parts of the bar will change the flow patterns and modify consequently the local sediment transport capacities. This will obviously affect the sedimentation pattern, also of the finest particles moving in suspension in the water column. The segregation of sediment fractions of both disposed and natural sediments will result in the formation of different substrata, some more silty than other, creating a variety of ecotopes.

## 4. RESEARCH ON THE WALSOORDEN TEST CASE

### 4.1. Tools and tests

PAET stated from the start [Peters & Parker, 2001] that field surveys, physical and numerical models needed to be combined, as each tools has advantages and limitations. They must be complementary tools for assessing the alternative dredging and disposal strategy. The research programme included field surveys (floats, sediment transport), physical, fixed-bed scale model tests including sediment tracking and hydrodynamic numerical model simulations. Flanders Hydraulics Research (Ministry of Environment and Infrastructure) implemented this programme with the support of the Port of Antwerp and its expert team.

### 4.2. Conclusion about the feasibility study of the Walsoorden test site

The results derived from the studies [Flanders Hydraulics Research, 2003] indicated that disposal of sediment as proposed for the morphological dredging strategy can likely be used to influence the estuarial morphology [PAET, 2003], with ecological benefit as degraded areas and their associated biotopes could be restored. PAET insisted on having a small scale in situ disposal test to gain final evidence that the proposed strategy is feasible. The analysis of the data has also shown that all the investigative tools were needed to reach this conclusion and that the morphological assessment should not be based on modelling alone. The present knowledge about and understanding of the physical processes governing morphological changes is still not sufficient to set up models that can be fully trusted. Combining different tools is the only way to reduce the uncertainties.

ProSes requested team was to give a second opinion and comment on the methodology used for and the results gathered from the research. They confirmed that the idea to use dredged material to restore sandbars is very valuable and that an in situ disposal test is necessary to remove the remaining uncertainties about the proposed strategy.

## 5. THE 2004 WALSOORDEN IN SITU DISPOSAL TEST

### 5.1. Execution of the disposal test

The aim of the in situ test was to dispose quietly and precisely 500.000 m$^3$ of sand with a diffuser on the bottom. The dredging vessel (self-discharging hopper dredger) was connected to a floating pipeline through which the sand is transported to a pontoon “Bayard II” (Figure 5). On this pontoon the sand is pumped to a diffuser (Figure 6) that disposes the sediment in a precise way on to the bottom. The use of the diffuser required an adjustment of the disposal license. The amount of 500.000 m$^3$ was chosen because it is on one hand large enough to affect significantly the bottom morphology, on the other hand small enough to be reversible if something would go wrong. The choice of the disposal location was based on the results of the feasibility study. The float measurements, the results of the numerical simulations and the physical scale model tests with moveable material on fixed bed indicated that an area between the northern sand spit and the tip of the plate was the most suitable one (Figure 7). From November 17th to December 20th 2004 500.000 m$^3$ of sand was almost continuously disposed in the proposed area.

### 5.2. Monitoring of the disposal test

To evaluate the success of the test an extensive monitoring programme was set up. This programme, which was executed over a period of one year, included bathymetric surveys, ecological monitoring, sediment tracing tests and sediment transport measurements. Several criteria were defined before the start for evaluating its success. One of them stated that 2 weeks after finishing the disposal, at least 80% of the sediment should stay within a control area defined as the disposal area, extended slightly towards the sandbar. Also the ecological parameters should not deviate from the ongoing natural trends.

Figure 6: detail of the diffuser

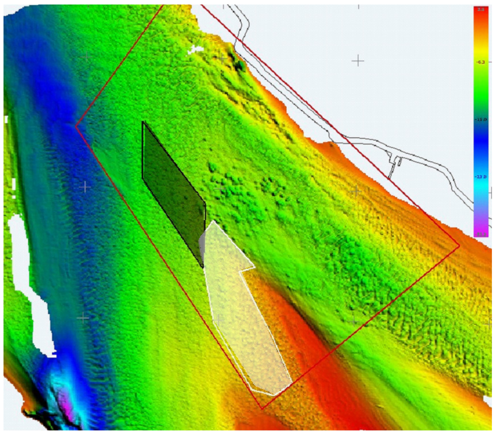

Figure 7: licensed disposal area (red) and disposal test areas (2004 = white, 2006 = black)

### 5.3. Bathymetric surveys

The multibeam bathymetric surveys produce high-resolution bathymetric charts. From November 2004 until March 2005, weekly surveys were executed in an area around the disposal location (area ~ 900 ha). From March until June 2005 the measurement frequency was reduced to one survey every 2 to 3 weeks, while from June 2005 until January 2006 one survey per month was executed. Beside this possible impact area, a larger zone was surveyed every 2 months to detect possible larger scale effects. These surveys allowed precise volume computations, which evolution is shown in Figure 8. A correction factor 0.9 was applied to the hopper volumes to account for to the differences in density in the hopper and in situ. The first survey after the execution of the disposal test shows a smaller volume measured in situ than what was disposed (see Figure 8) that represents the sediment losses during the disposal (25.000 m³), while a fraction (finer sands) was removed by the flow.

During the first 2 months the volume within the control area was even higher than after execution of the test, probably due to natural processes. Later on, a decrease of volume was measured, ~ 10% after 6 months, only about 20% after one year. The main part of the eroded sand is transported during flood towards the Walsoorden sandbar (Figure 9). This evolution is in agreement with the predictions of the feasibility study. It may be concluded that the disposed sediments stay well in place, and the imposed criterion was successfully fulfilled.

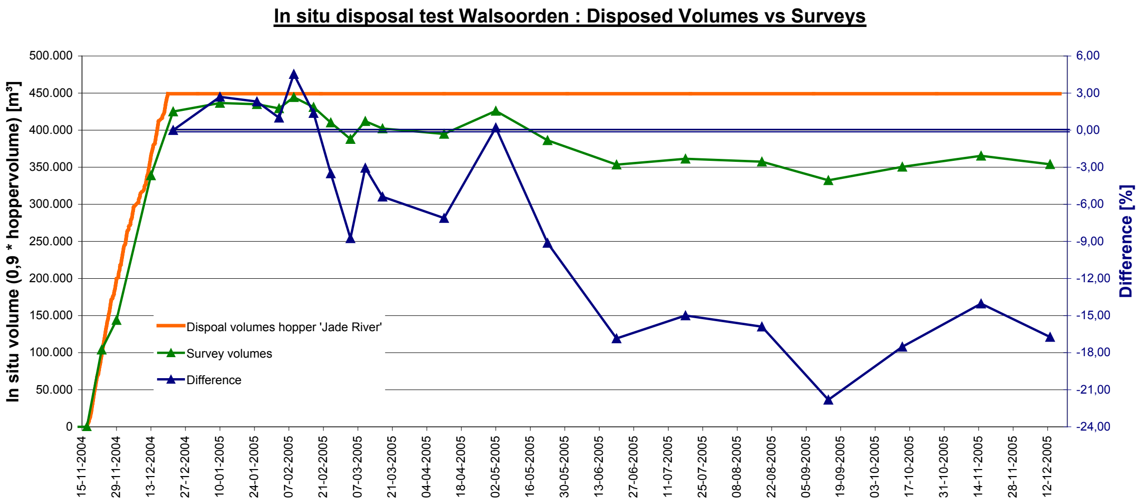


Figure 8: Evolution of measured volumes (orange: disposed; green: measured; blue: difference)

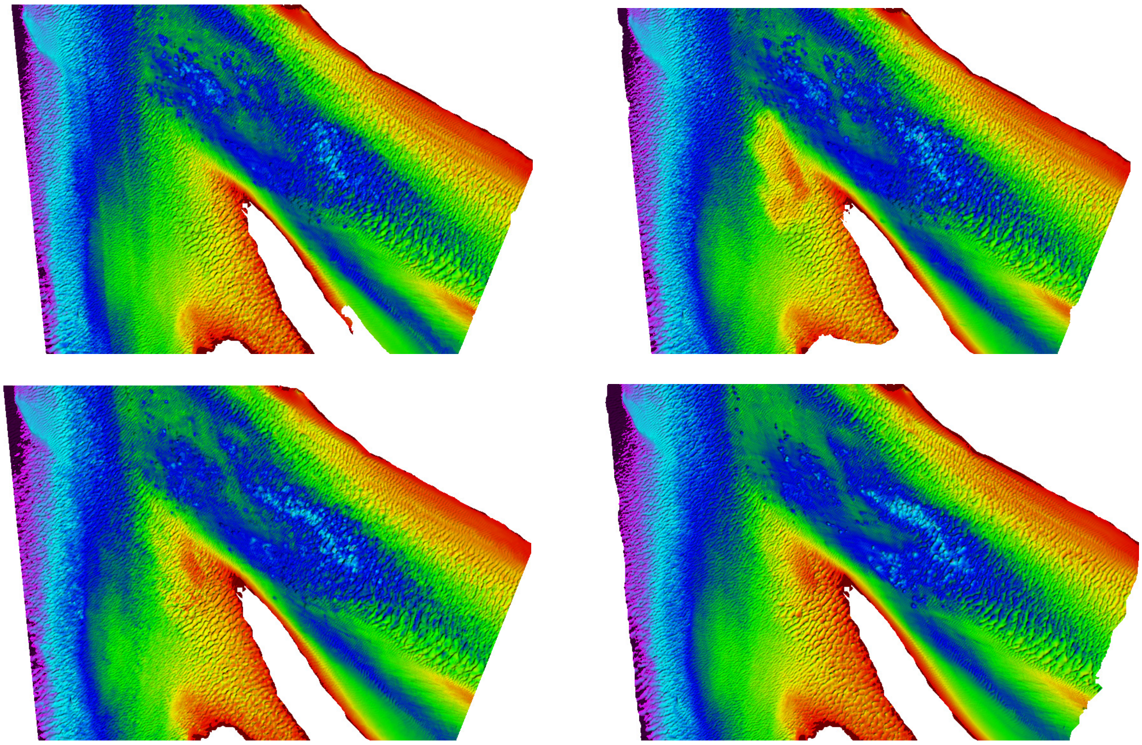

*Figure 9: Evolution of bathymetry (November–December 2004 (top), June–December 2005 (down))*

## 5.4. Ecological monitoring

The ecological monitoring programme included intertidal and subtidal surveys. Ecologists feared increased sedimentation, especially of coarser sediment on the sandbar, which could have a negative impact on its biotopes. The intertidal monitoring comprised of several stations on the Walsoorden sandbar where erosion-sedimentation, sediment composition and macrobenthos was measured. None of the results from this monitoring indicated that the in situ disposal test was responsible for a significant change in ongoing trends.

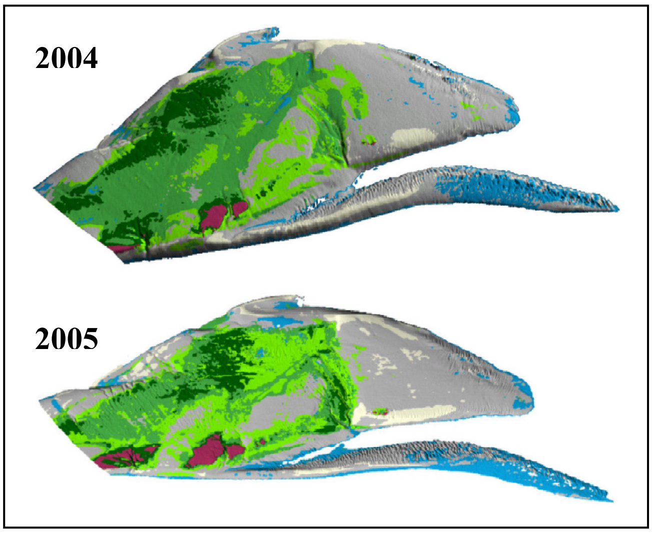


*Figure 10: Remote sensing image Walsoorden sandbar*

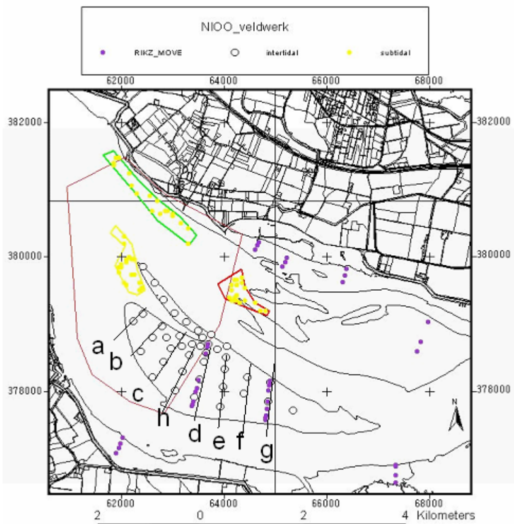


*Figure 11: Sampling stations ecological monitoring*

The subtidal monitoring was focussed on sediment composition and macrobenthos samples, using the BACI-technique (Before-After-Control-Impact). Beside the disposal area (yellow area on Figure 11), 2 control areas were chosen: one at the traditional disposal site "Schaar van Waarde" (green area), the other (red area) where no influence from disposal activities should be expected. For the subtidal samples an initial decrease in mud-percentage was found for the impact area. This is explained by the absence of finer mud material in the dredged sediments that were disposed. The macrobenthos samples did not show deterioration (biomass, diversity and density) for the impact area compared to the 2 other control areas.

### 5.5. Conclusions in situ disposal test

From morphological point of view, it can be concluded that the experiment using a diffuser for modifying the morphology of the sandbar by disposing precisely dredged material was very successful. The ecological monitoring did not reveal any significant negative impact, neither in the intertidal areas, nor in the subtidal areas. This in situ test confirmed the feasibility of the proposed disposal strategy.

## 6. THE 2006 WALSOORDEN IN SITU DISPOSAL TEST

### 6.1. Execution of the disposal test

In the beginning of 2006 a second disposal test was executed, using the traditional clapping technique with hopper dredgers (instead of the diffuser) just downstream the disposal location of 2004 (Figure 7). Because it was part of the routine maintenance dredging works of the Scheldt estuary, the disposal of 500.000 m³ was spread over a 3 months period.

### 6.2. Ongoing monitoring of the disposal test

The programme was extended and will be executed over a period of one year with bathymetric surveys and ecological monitoring similar to those of the 2004 disposal test. Again, morphological and ecological criteria were defined to evaluate its success.

The preliminary results of the bathymetric monitoring show that the second in situ test can be described as a success from morphological viewpoint. After 6 months only 32% of the dumped material has been moved out of the control volume (Figure 12). Preliminary analysis of the surveys indicates a transport of the material towards the Walsoorden sandbar. Material disposed in 2006 has reached the 2004 control area, leading to a nourishment of this area.

The ecological results will become available during the first half of 2007, with the preliminary results not showing any negative impact.

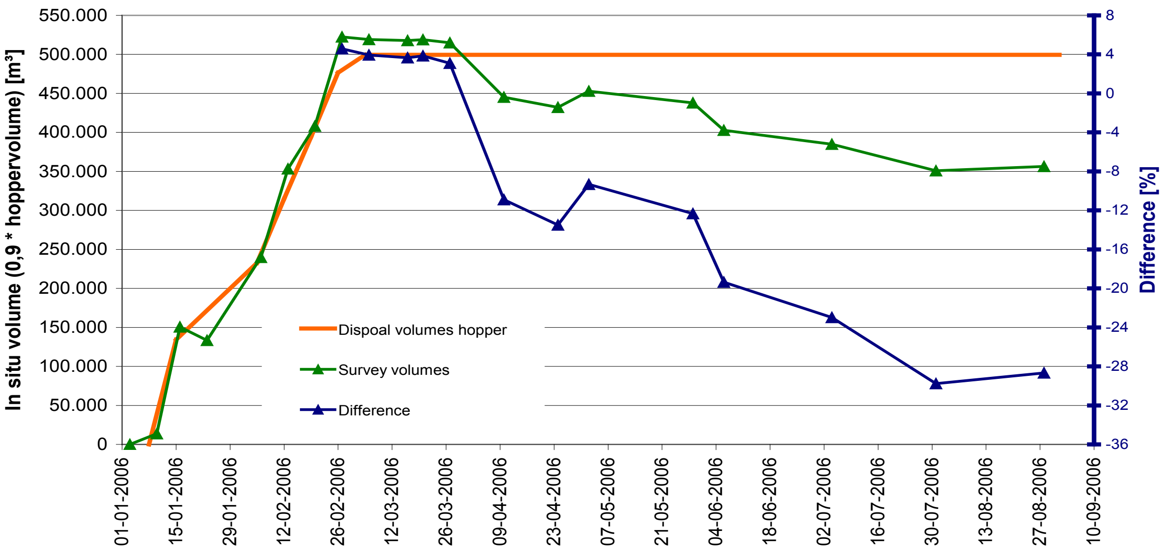


*Figure 12: Evolution of measured volumes (orange: disposed; green: measured; blue: difference)*

## 6.3. Preliminary conclusions in situ disposal test

Although the results of the monitoring campaign are only preliminary, the second disposal test seems to be a success as well. Although further investigations are necessary, these results are quite satisfactory and give confidence about a further implementation of the disposal strategy as was proposed by the PAET. In total an estimated volume of 3 to 5 million $m^3$ could be disposed near the Walsoorden sandbar to reach the proposed objectives. This amount represents 50% of the dredging quantities (7 $Mm^3$ in total) necessary for a further deepening of the navigation channel in the Western Scheldt.

# 7. CONCLUSION AND RECOMMENDATIONS

Dredging operations were considered as responsible for environmental degradation in the Western Scheldt, one of the last relatively natural estuaries with a dynamic multi-channel system and exceptionally valuable eco-systems. A management with broader objectives that includes accessibility, safety and nature preservation progressively replaces the past management of the maritime access route to the Port of Antwerp, which was based almost exclusively on an engineering approach. The international expert team appointed in 2001 by the Port of Antwerp authorities, set forward new ideas about the morphological management of the estuary by using dredging and disposal of dredged material to steer the morphological behaviour of the estuarine multi-channel system. The pilot project to demonstrate this new disposal strategy the location at the sandbar of Walsoorden was selected by the Port of Antwerp Expert Team on the basis of expertise. Modifying the shape of this sandbar by morphological dredging and disposal might improve the self-dredging capacity of a nearby crossing, reducing the dredging effort.

The feasibility of this project was studied by Flanders Hydraulics Research, combining desk studies, scale modelling, numerical modelling and field surveys and an in situ disposal test was conducted to confirm it. During 2 consecutive pilot tests, 500.000 $m^3$ of sand was disposed twice at the end of 2004 and at the beginning of 2006. Both experiments were intensively monitored, morphological as well as ecological. The results obtained till January 2007 confirm that a new morphological dredging and disposal strategy could be successfully embedded in the future morphological management of the Western Scheldt. However, as stated by the Port of Antwerp Expert Team, the new ways of dredging and disposing sediments should be combined with other measures, such as adapting the hard bordering of the estuary and finding alternatives to the traditional protection works of banks and shoals.

The Walsoorden experiment also confirmed the need for building the capacity of the professionals in morphological assessment techniques, giving sufficient room to expertise and visual analysis of charts, maps and remote sensing observations. A further collaboration between engineers, biologists and ecologists is needed to develop further the idea of morphological dredging and the strategies to manage the morphology of estuarine systems.

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