A SYNTHESIS ON THE ASSESSMENT OF AN ALTERNATIVE DISPOSAL STRATEGY TO SERVE SUSTAINABILITY IN THE SCHELDT ESTUARY

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Abstract: The Scheldt estuary is characterised by a valuable multiple-channel system consisting of sandbars in between primary and secondary channels. Within the framework of the Long Term Vision (LTV) for the Scheldt estuary the conservation of this multiple-channel system is defined as the key goal to achieve morphological sustainability.

Dredging is one of the human activities having an impact on morphology, hence dredging and disposal should be optimised by minimising the negative impact on morphology. The current disposal strategy for maintenance dredging consists mainly of disposing sediment into the secondary channels. As a consequence of the sustainability goal a maximum dumping capacity is assigned to each secondary channel in order not to exceed the natural bearing capacity of the multiple-channel Scheldt estuary.

The assigned yearly disposal capacity for all secondary channels together is sufficient to counter the yearly sediment volume arising from maintenance dredging operations. However, if the total sediment volume that is produced by the deepening of the navigation channel towards Antwerp would be disposed into the secondary channels, the conservation of the multiple-channel system would not be guaranteed. To anticipate on this expectation, shallow water sandbar slopes have been proposed as an alternative disposal location. The use of these alternative disposal locations provides an increase in the estuary's disposal capacity without increasing the disposal intensity in the secondary channels and is expected to enlarge the area of shallow water habitats, creating opportunities for ecosystem development.

The feasibility of this proposal has been investigated by desk studies on historical maps, by field measurements, by physical scale model tests and by numerical simulations and has been confirmed by two in situ experiments. Consequently, the alternative disposal locations will be used during the deepening of the navigation channel towards the port of Antwerp. As a result of the adaptation of the disposal strategy, the conservation of the valuable multiple-channel system in the Scheldt estuary is not endangered by dredging and disposal operations.

Keywords: morphological dredging, disposal strategy, long term vision, sustainability, Scheldt estuary

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1 THE LONG TERM VISION: A FRAMEWORK FOR SUSTAINABILITY

The Long Term Vision for the Scheldt estuary (DZL and AWZ, 2001) is a joint Flemish-Dutch vision which offers the foundations for the development of a bilateral policy for the Scheldt estuary and provides the framework towards a sustainable management of the Scheldt estuary. The main goal is the development of a healthy and multifunctional estuary that is used for human needs in a sustainable way. The Long Term Vision focuses on three principal utility functions: (1) safety against flooding, (2) navigable access to harbours and (3) naturalness of the physical and ecological system. The estuarine morphology influences all three utility functions and is given a central place within the Long Term Vision. In terms of morphology, the main goal is translated into the conservation of the multiple channel system in the Western Scheldt, which is advantageous for and closely related to the estuary's principal utility functions. The Long Term Vision explicitly states that a well-considered dredging and disposal strategy can contribute substantially to the conservation of the multiple channel system.

This paper describes the step-by-step process towards the assessment of an alternative disposal strategy in the Scheldt estuary, which helps in attaining the morphological sustainability goal as postulated by the Long Term Vision. However, the application of the alternative disposal strategy alone may not be enough to ensure the multiple channel system of the Scheldt estuary in 2030.

2 PROPOSAL FOR A NEW MORPHOLOGICAL MANAGEMENT STRATEGY

2.1 The concept of morphological dredging

By the end of 1999, the Port of Antwerp called on a team of international experts to provide advice on the feasibility of a further deepening of the fairway in the Western Scheldt between Antwerp and the North Sea. The so called Port of Antwerp Expert Team (PAET) first studied the historical evolution of the Western Scheldt in order to gain the broader perspective on the status of the Western Scheldt at that time. This study resulted in a Baseline Report (Peters et al., 2000) that served as a background document for discussions held together with the LTV cluster morphology about possible future evolutions and as a foundation to establish the PAET's ideas about the morphological management of the Western Scheldt (Peters et al., 2001). The PAET defined the need for a morphological management strategy based on a thorough understanding of the natural physical processes within the estuary and stated that conservation and redevelopment of morphological diversity would be an important tool to satisfy the policy requirements of accessibility, safety and naturalness.

One of the questions the Port of Antwerp addressed to the PAET focuses on the relation between dredging activities and the morphological evolution of the Western Scheldt. By proposing dredging as a tool to steer morphological evolutions, this question was answered in a positive way. The PAET was convinced that dredging and disposal of sediments, as a part of a well-considered morphological management strategy, could be used as a tool to preserve the estuary's morphological diversity, represented by the complexity of its channel and sandbar system, and to enhance the self dredging efficiency of the crossings in the navigation channels (Peters et al., 2001).

2.2 The alternative disposal strategy

Based on their historical analysis of the Western Scheldt (Peters et al, 2001a and 2001b), the PAET proposed the Walsoorden sandbar as the best suited location for a pilot project. During the past decennia the seaward tip of this sandbar had been eroded away. As a consequence the morphology of the area around the Walsoorden sandbar evolved towards a single channel system, being a situation which is not compliant with the sustainability goals postulated in the Long Term Vision.

Therefore, the PAET proposed to reshape the seaward tip of the Walsoorden sandbar by disposing sand material originating from the dredging works in the estuary. By doing so, the flood and ebb flows would continue to maintain the multiple channels (Peters and Parker, 2001). Besides making the estuary ecologically (by reducing the currents on the ecological valuable intertidal areas) and morphologically (by maintaining the multiple channel system) healthier, the reshaping of the sandbar would also improve the self-erosive capacity of the flow on the crossing and possibly reduce the quantity of material to be dredged. A trial and error approach with careful monitoring of the movements of the disposed material is included in the proposal. Before a pilot project at the downstream tip of the Walsoorden sandbar could be started, it was subjected to a severe feasibility study to investigate the weaknesses and opportunities of the proposed alternative disposal strategy.

3 THE FEASIBILITY STUDY

3.1 A multidisciplinary research program

Flanders Hydraulics carried out a research program to evaluate the feasibility of the proposed pilot project at the Walsoorden sandbar. The research program included a field measurement campaign with DGPS-floats, in-situ sediment transport measurements, the use of a physical scale model for both hydrodynamic modelling and moving sediment tests and the use of a numerical model for hydrodynamic simulations. Each of the used study tools has advantages and limitations. The combination allows a complementary assessment of the feasibility of the proposed alternative disposal strategy.

None of the results indicated that the idea would not be feasible. In the following phase research was executed to find the location that was most suited for the execution of an in situ disposal test. Therefore a fixed-bed scale model with artificial sediments was used to investigate sediment transport pathways. The limited distortion of this fixed-bed scale model allows a good representation of three dimensional flow patterns and large scale turbulence. These phenomena can not be represented well in numerical flow models. Sediment transport investigation (Fig. 1) revealed that an area in the Minor Northerly Flood channel (MNF) close to the tip of the Northerly Sand Spit (NSS) is capable of maintaining large amounts of sediment and that disposal of dredged material on top the Eroded Tip of the Walsoorden sandbar has to be avoided (Meersschaut and Verelst, 2003). Hence, disposal is advised to be applied always on the Northern Sand Spit in further stages of implementing the alternative disposal strategy.

Finally, the effect on flow patterns of a reshaped sandbar was studied by a numerical flow model. The numerical flow model was able to reproduce flow vectors correctly in the deeper channels, but deviations occurred in shallower areas. Results of simulations with a restored tip of the Walsoorden sandbar clearly show an increase in flow velocity around the Walsoorden sandbar (Meersschaut and Verelst, 2003). The strongest increase happens to occur in the Main Flood Channel (MFC) during flood periods, which is one of the expected results of applying the proposed alternative disposal strategy.

3.2 Conclusions about the feasibility study

Not all aspects of the study, that were indicated by the PAET as being essential for assessing the feasibility of the proposed disposal strategy, could be undertaken However, the results derived from the study concerning hydrodynamics and sediment transport [Meersschaut and Verelst, 2003] indicated that the disposal of material as proposed for the morphological dredging strategy can likely be used to influence the estuarine morphology [PAET, 2003]. Degraded areas and their associated biotopes could be regenerated. 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 investigative tools were needed to reach this conclusion and that morphological assessment of the Western Scheldt should not be based on modeling alone. One should realise that our knowledge about and understanding of the physical processes governing morphological changes is still not sufficient to set up trustworthy models. Combining different tools is the only way to reduce the uncertainties. Where most of the research occurred within the scope of ProSes, a second opinion team was asked to give their comments 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 (Berlamont et al, 2003).

4 THE FIRST PILOT STUDY (2004)

The next step in the assessment of the alternative disposal strategy is the setup of a pilot project which must be well documented and thoroughly monitored (Meersschaut et al., 2004). The pilot project consists of an in-situ disposal test of 500.000 m³ of sand material in the Minor Northern Flow channel (MNF) near the Northern Sand Spit (NSS), being within the limits of the licensed disposal zone (Fig. 2). The complete restoration of the Eroded Tip of the Walsoorden sandbar does not fall within the scope of the pilot study (Meersschaut, 2004).

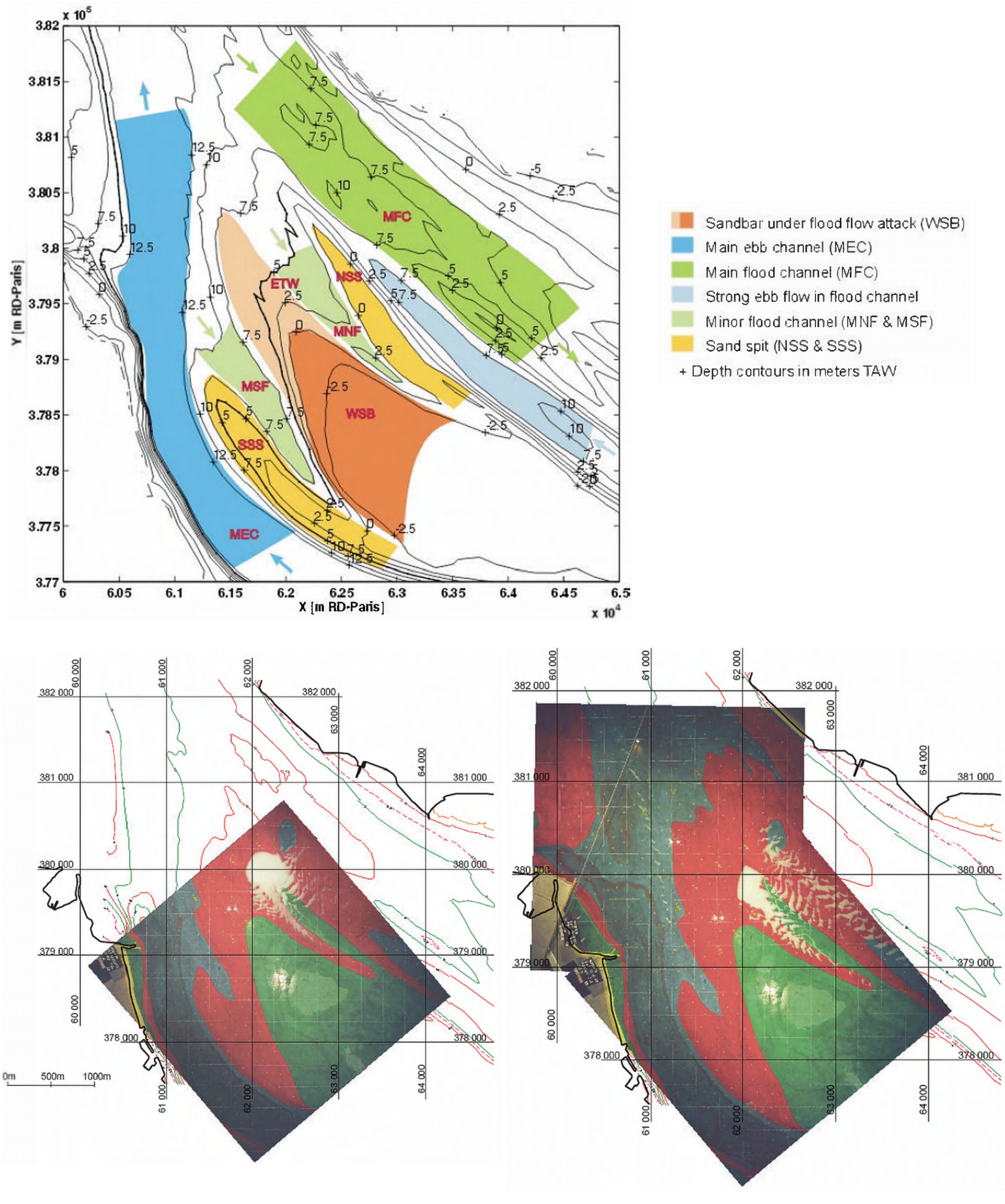

Figure 1 Above: Overview of the area around the tip of the Walsoorden sandbar and nomenclatura of the main morphological features. Below: Disposal experiment near the tip of the Walsoorden sandbar in the physical scale model. (From: Meersschaut and Verelst, 2003)

4.1 Setup of the first pilot study

The amount of dredged material to be disposed must be large enough in order to detect significant changes in bathymetry. On the other hand the morphological evolution initiated by the pilot study must be reversible if negative effects would occur. An amount of 500.000 m³ sediment was agreed on to fulfil both of the mentioned arguments.

The sediment disposal is executed in November and December 2004 with the use of a diffuser, which is the reverse process of dredging sediment with suction hopper dredger. Advantages of this more expensive technique are the more accurate sediment release just above the river bed and the limited increase in turbidity in the water column.

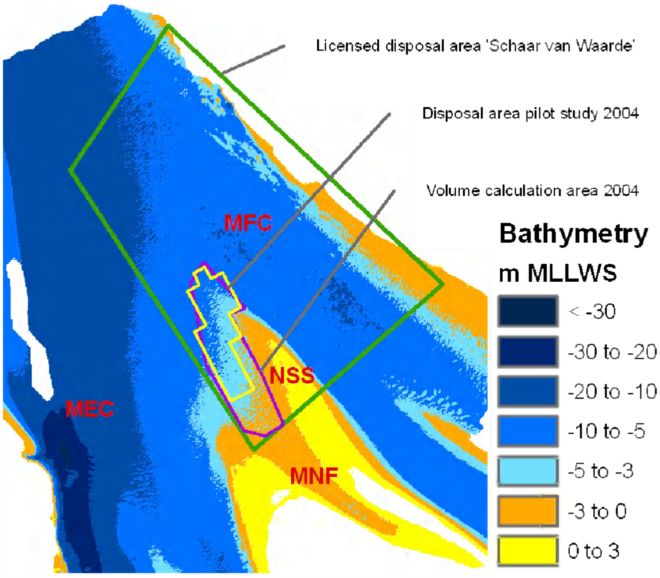

Figure 2 Overview of the licensed disposal area 'Schaar van waarde' at the northern tip of the Walsoorden sandbar. The disposal area used in the first pilot project is indicated in yellow. Bathymetry of November 2004.

The evaluation criteria to determine the success or failure of the pilot study were made up in advance (Ides et al., 2006) during discussions between morphological and ecological experts. Two morphological and three ecological evaluation criteria were selected (Table 1). A morphological and an ecological monitoring program are executed to provide the necessary data to evaluate the pilot study.

Table 1 Evaluation criteria for the first pilot project

Morphological criteria	**Ecological criteria**
1. two weeks after disposal 80% or more of the disposed sediment must reside on the disposal location	1. sedimentation on the Walsoorden sandbar must not deviate from the observed long term trends
2. sedimentation in the secondary channel is limited to 15% of the cross section	2. the silt content of intertidal areas may not change significantly
	3. density, biomass and diversity of the intertidal macrobenthos community may not deviate from observed long term trends

4.2 Morphological monitoring program

The aim of the morphological monitoring program is to keep a close eye on the morphological evolutions by rapid detection of possible negative evolutions. The morphological monitoring program includes repeated multibeam echo sounding surveys and occasional lidar (light detection and ranging) flights. The severe technical specifications imposed to the multibeam monitoring program were never realised before (Leys et al., 2006).

The set of consecutive multibeam surveys allows the visualisation of the disposed sediments and the evolution thereafter. Fig. 3a-c shows the bathymetry respectively in November 2004, December 2004 and December 2005. The accretion due to the sediment disposal is clearly seen on Fig. 3d, while Fig. 3e shows the bathymetric evolution in the year after completion of the first in situ disposal test. Note that sediment erosion occurs within the limits of the disposal area and sediment deposition can be seen between the disposal area and the sandbar, as was expected and predicted by the physical scale model. In Fig. 3e can be observed that the area around the tip of the Walsoorden sandbar is a highly dynamic area. Sediment transport happens by means of dune migration: this transport mechanism is also governing the freshly deposited dredging material. Within the routine disposal zone in the secondary channel (Fig. 3e, polygon bordered with black line) the deposits from the maintenance dredging works in 2005 can be detected.

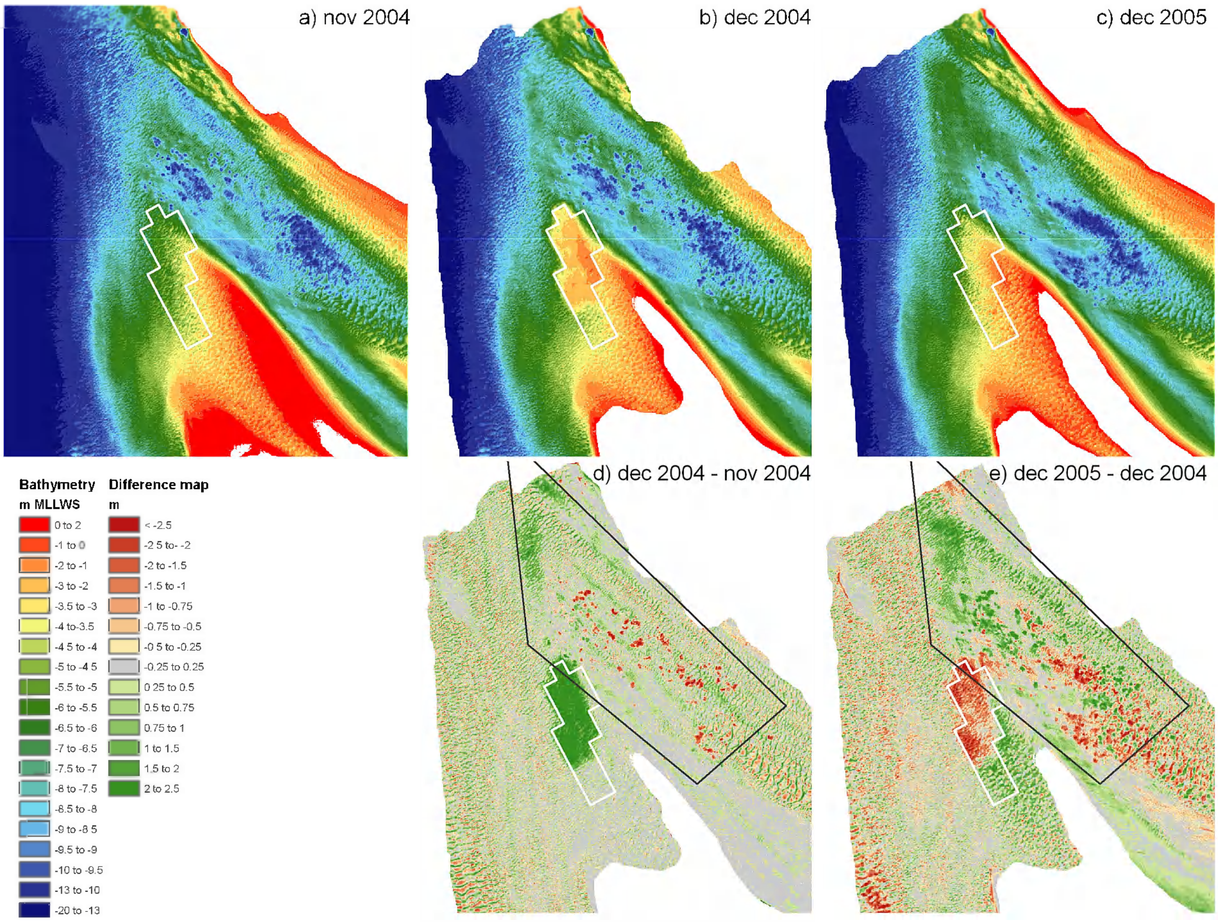

Figure 3 Consecutive mutibeam surveys and deduced difference maps show the evolution of the sediment transport in the immediate environment of the pilot project area. The 2004 disposal zone is indicated in white. The routine disposal zone is indicated in black.

Volume calculations were performed in a control zone on and around the disposal zone, for every multibeam survey in between November 2004 and December 2005 (Fig. 4). The evolution of the sediment volume inside the volume calculation area shows that 1 year after completion of the in-situ disposal test more than 80% of the disposed sediment is still within the boundaries of the volume calculation area. Considering the criteria for assessing the success of the experiment, two weeks after completion of the disposal test even more than 100% was detected at the disposal site instead of the 80% limit which was imposed by experts (Fig. 4). Sediment accretion in the secondary channel is limited to a maximum of 3.7% of the cross section, well below the 15% given in the criteria (Table 1) (Ides et al., 2006, Plancke et al., 2006). Both the morphological and the ecological criteria are fulfilled.

4.3 Ecological monitoring program

The aim of the ecological monitoring program is the detection of changes in the subtidal and intertidal macrobenthos community due to the in-situ disposal test. These changes are related to changes in relevant abiotic parameters as measured by existing long term monitoring programs. The macrobenthos community has an essential role in the estuary's ecology and is very sensitive to environmental changes, which makes the macrobenthos community a key parameter for detection of ecological changes.

The ecological monitoring program consists of subtidal and intertidal change monitoring. In the subtidal area, a BACI (Before – After – Control – Impact) design was applied for macrobenthos sampling and determination of sediment particle size distribution. The BACI design aims at detecting changes due to a certain impact. In this case, changes in the macrobenthos community in the disposal zone (impact location) are compared to changes in the macrobenthos community observed in a control zone free of disposal activities. The BACI design allows elimination of changes caused by external effects. In the intertidal area, changes in particle size distribution, silt content and the occurrence of the macrobenthos community are compared to long term trends. Forster et al. (2006) conclude that none of the observed effects is significant or can be distinguished from the long term trends.

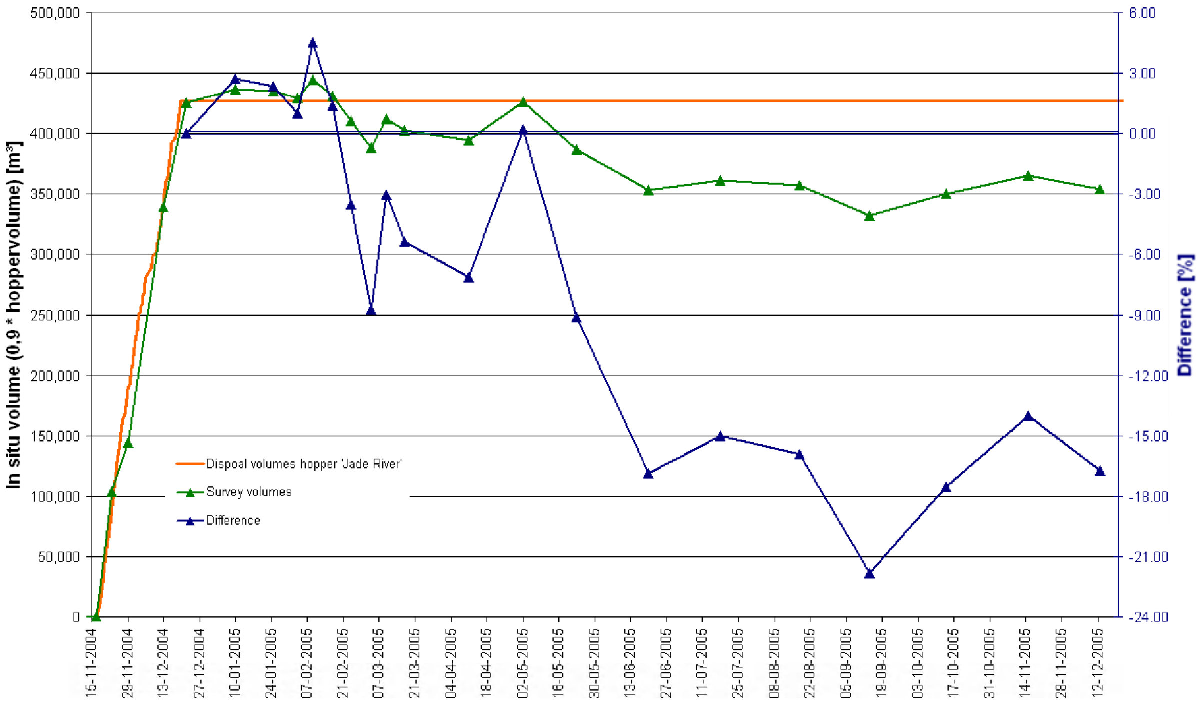

Figure 4 Evolution of the disposed sediment inside the volume calculation area. The threshold of 20% reduction in sediment volume is exceeded 9 months after disposal, which is much longer than the imposed morphological criterion of only 2 weeks. (From: Ides et al., 2006)

4.4 Sediment tracing test

The sediment tracing test aims at observing the local sediment transport at the disposal location. A sediment tracer test is expected to indicate whether or not the disposed sediment is mobile and to reveal sediment transport directions and sedimentation areas in case of mobile sediment. An amount of tracer was injected within the disposal zone in February and September 2005. Sediment samples were taken one day and one month after injection. However the sediment tracing test was not very successful since only a very small part of the injected tracer was recovered, the limited results of the tracer test indicate a preference transport direction towards the Walsoorden sandbar (Haecon-Soresma, 2006).

4.5 Conclusions from the first pilot study

All morphological and ecological evaluation criteria, which were defined in advance, are evaluated positively (Ides et al., 2006, Plancke et al., 2006). Most of the disposed material remains within the boundaries of the disposal location, a small part moves towards the sandbar. Within one year after the disposal test, no significant negative ecological changes were observed that could be addressed to the pilot study (Forster et al., 2006). The in situ disposal test significantly changed the sediment particle size at the disposal location, but caused no significant changes in the macrobenthos community, which was already very poor before the start of the in situ disposal test (Forster et al., 2006). In the intertidal area, on the Walsoorden sandbar, no remarkable changes were observed because most of the disposed material remained within the original disposal location. The pilot project confirms that a well-considered disposal management may contribute to a sustainable morphological management.

5 THE SECOND PILOT STUDY (2006)

5.1 Setup of the second pilot study

A second in situ disposal test was conducted in 2006 with a slightly different setup. The dredged sediment is not disposed with a diffuser anymore, but is released directly from the dredger. The first pilot study has proved that the disposed sediment was stable enough to allow the usual disposal technique which requires a disposal area with larger depths than in the disposal area used in the first pilot project. Based on validated model flow velocity calculations and the field data set gathered in 2003, Flanders Hydraulics advised a new disposal test area adjacent to the disposal area used in 2004 (Fig. 5) and within the limits of the licensed disposal area (Ides and Plancke, 2005).

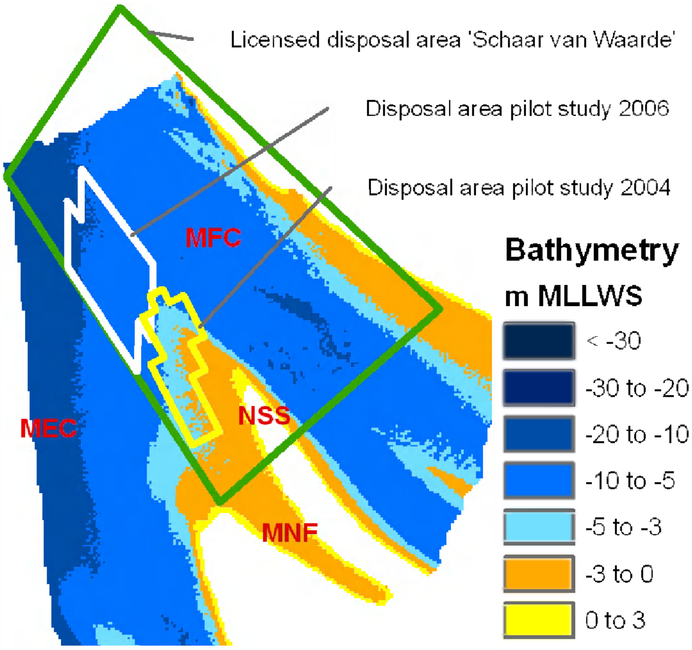

Figure 5 Overview of the immediate environment of the first and the second pilot study. Bathymetry of January 2006.

The second pilot study occurred in two phases. The first phase is the disposal of an amount of 500.000 m³ in January and February 2006, the second phase consists of the disposal of 770.000 m³ from September to December 2006 (Fig. 6a-c). These disposals were carried out within continuous maintenance dredging works in the Western Scheldt.

Like in the first pilot study, both an extensive morphological and ecological monitoring program are carried out. The duration of the monitoring program is oriented on the longer term. The monitoring program for the second pilot study will continue until the start of the planned sediment disposals resulting from the deepening of the Western Scheldt's fairway. The disposal test will be considered as successful when the majority of the disposed sediment remains at the disposal location or moves towards the Walsoorden sandbar, i.e. remains within a polygon determined in advance.

5.2 Results from the morphological monitoring program

The disposed sediment of the first (Fig. 6b-c) and the second (Fig. 6f-g) phase of the second pilot study are clearly visible. No clear sedimentation pattern can be observed after the first phase (Fig. 6e). The period in between the two disposal phases may be too short to observe any significant sediment transport pattern. Nonetheless, the morphological evolutions over a period of 15 months (December 2006 – March 2008) after the second phase can be well distinguished (Fig. 6i). Sediment from the 2006 disposal site is clearly transported towards the Walsoorden sandbar.

In the Main Flood Channel an intense sedimentation area (Fig. 6i) can be detected, which is the result of the 2007 maintenance disposal. Although monitoring of the 2006 pilot study was still going on, there was a need for disposing fresh dredging material in the licensed disposal zone 'Schaar van Waarde'. It was not wanted to distribute sediment disposal transversally over the secondary channel, because the concept of the alternative disposal strategy consists of reducing or even stopping sediment disposal in secondary channels as to maintain its hydraulic capacity. Sediment disposal in the pilot study zones was also not wanted in order not to disturb the ongoing monitoring. Consequently, the 2007 maintenance disposal zone is chosen where the conditions just described are fulfilled in the best way possible (Fig. 6i).

Another sedimentation area can be distinguished north of Northern Sand Spit in Fig. 6i. This sedimentation area is not due to the disposal of dredged material. The relation between this sedimentation area and the pilot projects remains a subject of further investigation.

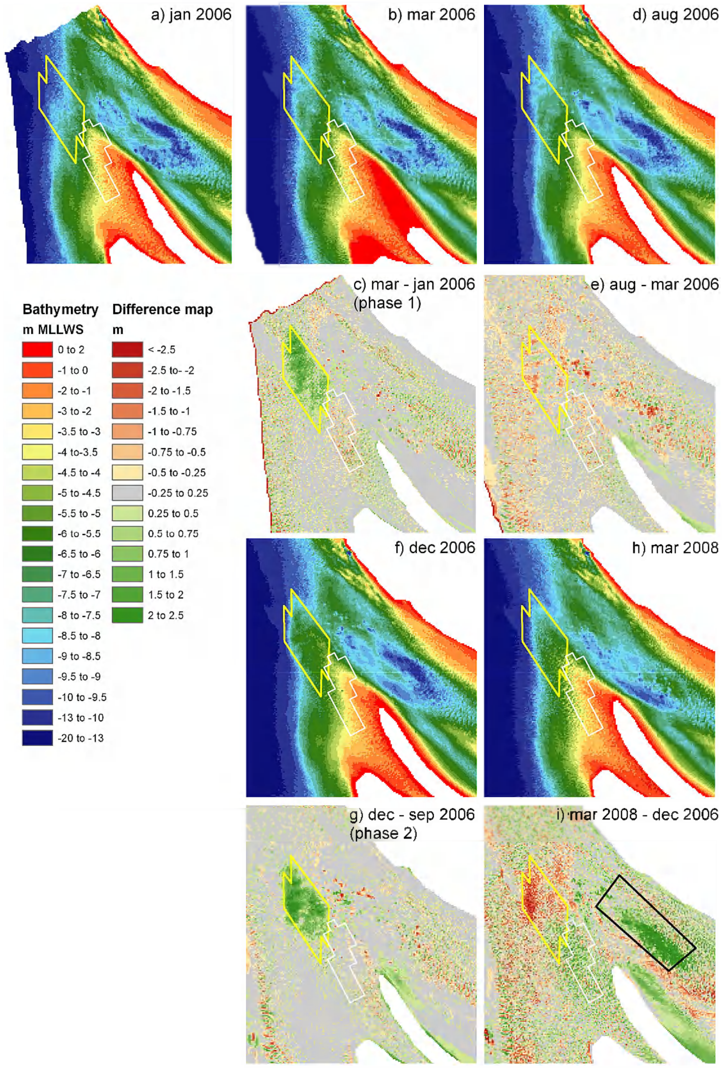

Figure 6 Consecutive multibeam surveys and deduced difference maps show the evolutionof the sediment transport in the immediate environment of the pilot project area. The 2004 disposal site is indicated in white, the 2006 disposal site in yellow. The 2007 maintenance disposal site is indicated in black in Fig. 6i.

Volume calculations were performed in a zone around the disposal zone for every multibeam survey in between January 2006 and March 2008 (Fig. 7). The evolution of the sediment volume inside the control area shows that the sediment disposed within the 2004 control area increases to 30% more than after the first pilot project. The sediment volume inside the 2006 control area decreases to less than 50% compared to the in-situ volume observed right after the second pilot project. A significant amount of sediment is transported away from the 2006 disposal zone can be found within the limits of the 2004 disposal zone or even further towards the Walsoorden sandbar.

5.3 Results from the ecological monitoring program

The ecological monitoring program of the first pilot study is continued considering both the first and the second disposal as an impact zone. The subtidal macrobenthos community remains the indicator in ecological evaluation because of its essential role in estuarine ecology and its sensitivity to environmental changes. Together with the subtidal macrobenthos community (Fig. 8) relevant environmental parameters (e.g. sediment composition, silt content, …) are monitored. After a monitoring period of 2.5 years, the same conclusions as after the first pilot study are withdrawn from the ecological monitoring program. No significant negative effects that can be related to the pilot projects are observed in subtidal or intertidal ecology (van der Wal et al., 2007).

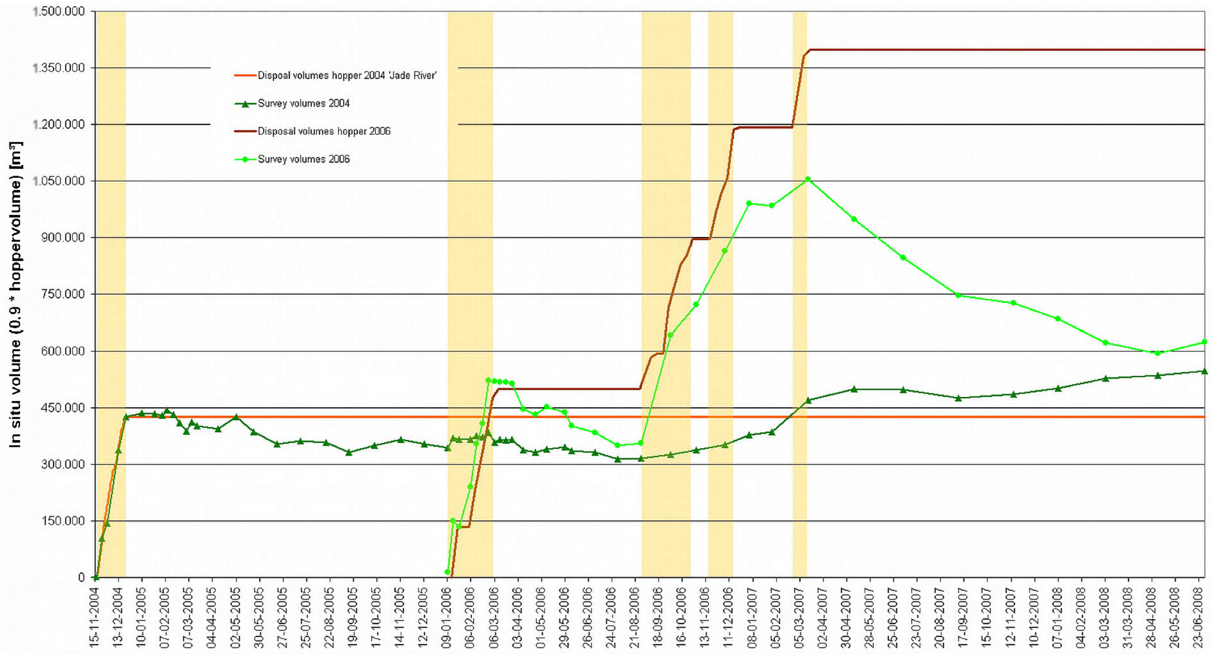

Figure 7 Evolution of the disposed sediment inside the volume calculation areas. The periods marked in orange delineate (the phases of) the in-situ disposal tests.

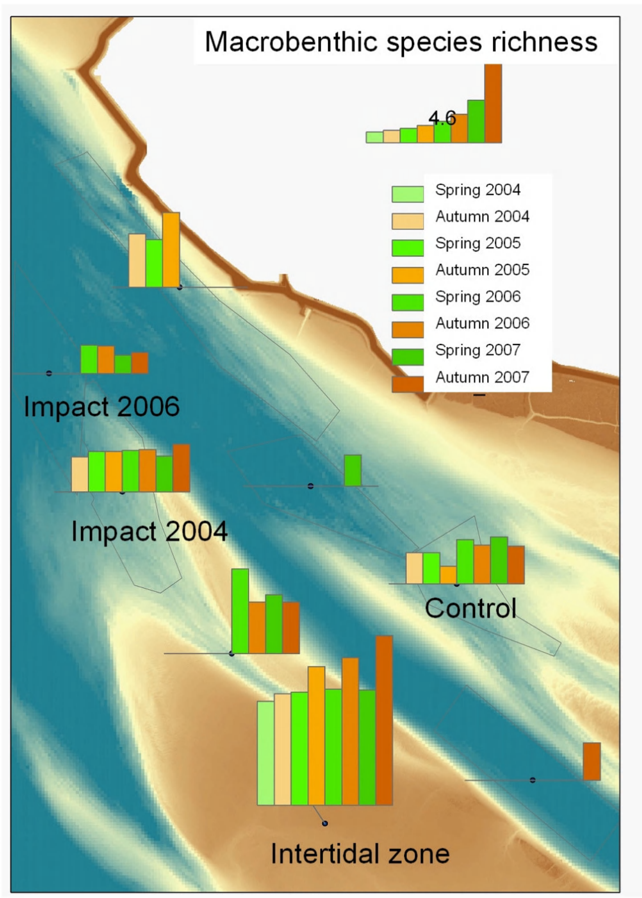

Figure 8 Evolution of the macrobenthos species richness in the subtidal impact (disposal) and control zones and on the intertidal Walsoorden sandbar over a period of 4 years. (From: van der Wal et al., 2007)

6 LARGE SCALE APPLICATION OF THE ALTERNATIVE DISPOSAL STRATEGY

The current disposal strategy for maintenance dredging consists of disposing sediment into the secondary channels. A maximum disposal capacity is assigned to each secondary channel in order not to exceed the natural bearing capacity of the multiple-channel Scheldt estuary. The assigned yearly disposal capacity for all secondary channels together is sufficient to counter the yearly sediment volume arising from maintenance dredging operations. If the total sediment volume that is produced by the deepening of the navigation channel towards Antwerp would be disposed into the secondary channels, the conservation of the multiple-channel system could be jeopardised.

The proposed alternative disposal strategy, which was investigated intensively on the Walsoorden sandbar, is also applicable on other locations in the Scheldt estuary. It has now been incorporated in the executive plan of the deepening of the navigation channel towards the port of Antwerp. Detailed site investigations of three potential disposal zones, all located at the edge of sandbars, are presently carried out (Plancke et al., 2008a and 2008b, and Ides et al., 2008). These locations are (1) Rug van Baarland, (2) Hooge Platen Noord and (3) Hooge Platen West (Fig. 9). The detailed site investigation points out that the alternative disposal strategy is applicable on the selected locations (Plancke et al., 2008b). The location Hooge Platen West resembles well to the disposal location at the Walsoorden sandbar, because both locations are influenced by flood currents. In contrary to the Walsoorden sandbar, Hooge Platen West is influenced by larger hydrodynamic conditions and by an important wave action originating from the mouth area. The locations Hooge Platen West and Rug van Baarland are sheltered from the ebb currents by the existence of a sand spit.

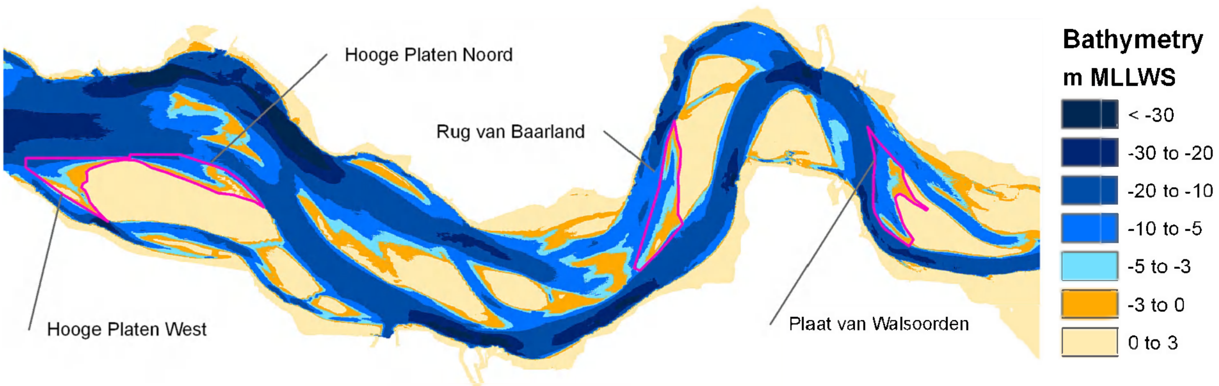

Figure 9 Position in the Western scheldt and bathymetry of the Walsoorden sandbar and the three new disposal sites where the alternative disposal strategy will be applied during the capital dredging of the deepening of the Scheldt.

7 CONCLUSION

The Long Term Vision for the Scheldt estuary presents a view on the preferred functioning of the system, accepted by both the Dutch and the Flemish government. The Long Term Vision acknowledges that the dynamic state of the estuary is strongly impacted by a range of human interventions including land reclamation, defence and training works, channel deepening and sand extraction. The Long Term Vision states that further interventions should not endanger the preservation of the existing dynamic evolution of the multiple-channel estuary.

The Port of Antwerp expert team (PAET) also recognises the essential role of morphology to harmonize safety, accessibility and naturalness. Morphological diversity in the Western Scheldt can be attained by a well-considered morphological management, of which an alternative disposal strategy should be an essential part.

A thorough understanding of morphological behaviour can only be obtained by a thorough analysis of historical data and of experience gained by field observations and measurements, supported by the interpretation of physical and numerical modelling results. During the Walsoorden pilot study (2001-2003), all these investigation tools were combined to assess its feasibility and the results sustained the concept of the alternative disposal strategy as proposed by PAET in 2001. The execution and extensive monitoring of two small-scale in-situ disposal tests was needed to confirm this proposal. As the alternative disposal strategy has been validated, it will be applied on a large scale during capital dredging works of the deepening of the Scheldt and during the maintenance dredging works thereafter.

This step-by-step assessment of an alternative disposal strategy shows that the realisation of a new concept needs many efforts for validation and acceptation. The approved alternative disposal strategy is not the only tool for attaining morphological diversity in the Scheldt estuary. Research for other alternative dredging and disposal strategies should continue. Also the possibilities for adaptation of river training works must not be forgotten, because river training works determine the boundary conditions for the future morphological development.

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