Port of Antwerp Expert Team

Alternative Dumping Strategy

The Feasibility of Morphological Dredging as a Tool for Managing the Westerschelde

Report by the Port of Antwerp Expert Team

(Draft for discussion)

September 15th, 2003

FOREWORD

This report is written at the request of ProSes by the expert team appointed by the Port of Antwerp (PAET), in order to have the opinion of the PAET experts about the feasibility of the alternative dredging strategy.

This report was prepared with the financial support of the Port of Antwerp Authorities. The opinions expressed in this document are those of the expert team and do not necessarily represent the official viewpoint of the Port Authorities.

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SUMMARY

In 2001 the Port of Antwerp Expert Team (PAET) proposed an alternative strategy for disposing of dredged material – either from maintenance or from capital dredging – and combining this with the long-term management of morphological development in the Schelde estuary [*PAET, 2001b*]. The PAET has also suggested that, even without a further deepening of the navigation channel, this alternative way for handling the sediments presently removed by maintenance dredging in the fairway crossings is urgently needed for conserving and improving the ecological values of the Westerschelde. At this time no information, which has arisen in the course of the studies of this proposal, indicates that this is not operationally practical. Available information suggests that it is likely to prove technically feasible and environmentally beneficial.

Initial field observations, physical modelling, numerical simulations and preliminary observations of sediment movement indicate that the proposed strategy is likely to be successful. Despite this positive indication, the importance of this issue for the management of the whole estuary is such that the PAET consider that, before the final decisions concerning the dredging/disposal strategy can be taken, the last step should be full-scale in situ disposal tests. Detailed monitoring of such tests will allow for unambiguous validation of these present positive indications. One of the key monitoring technologies, (high-speed multibeam surveying) has been demonstrated successfully on the proposed Walsoorden test site. Thus any real-life tests of dumping dredged materials and the induced morphological effects can be monitored in near real time.

The presentation by dredging contractors shows that the technology, methodology and operational capability for controlled deposition of sand material, as proposed by the PAET, already exists. It has been tested in real project situations much more difficult than those likely to occur in the Schelde.

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1. Introduction

An introductory comment: the word “morphology” is too often misused. Morphology is much more than flow and sediment transport. Theories about sediment transport are not proven and formulas uncertain. Theories about morphodynamic behaviour of natural rivers are even less certain. Is this a reason to remain undecided? Is it not better to build up experience with recurrent, reversible measures?

1.1. Background

In 1999 the Dutch and Flemish governments decided to set up a Long-Term Vision (LTV) project on the Schelde estuary. Three objectives were proposed: maximum safety against flooding, optimal accessibility of the ports within the estuary and nature development. These three fundamental subjects are interrelated by the morphology of the estuary. During the discussions in the LTV’s “morphology” working group, in 2000, the Port of Antwerp Expert Team (PAET) presented its ideas regarding the use of morphological dredging as an alternative to the present dredging strategies.

On the basis of past practical experience, the PAET members have suggested that an approach should be sought integrating necessary maintenance dredging and capital dredging with a controlled strategy for disposal of dredged material within the estuary. Such an approach provides a sustainable alternative to the existing practices or proposals, among other alternatives, of the disposal of sediment outside the Schelde estuary. In particular the PAET considers the disposal of sediment outside the estuary, rather than its use for managed morphological rejuvenation and development within the estuary, is strategically unwise and environmentally unsustainable.

In May 2001, the PAET presented their alternative dredging strategy in an addendum to their final report, written for the Port of Antwerp in the frame of the LTV project [PAET, 2001a&b]. This document and other more recent documents point out that the exact causes for the past morphological changes are complex and involve the continuing, natural, long-term evolution of the estuarial morphology due to past sea level rises, the morphological consequences of the effects of reclamation and engineering works on the tidal and hydrodynamic regime of the estuary and the ongoing effects of dredging. The exact interrelationships and balance of all these factors is not clearly understood; dredging is not to be seen as the only, nor even as the major, cause for the degradation of the Westerschelde morphology and ecology. In the addendum [PAET, 2001b] the PAET suggested Walsoorden as a test-site to investigate their idea of the alternative dredging strategy.

In May 2001 the Flemish government decided that the idea of an alternative dredging strategy had to be investigated and the Flanders Hydraulics Laboratory in Borgerhout (FHL) was requested to conduct a study with the assistance of the PAET.

The PAET is very strongly of the opinion that this issue must be approached by combining field surveys with both physical scale models and numerical models. The PAET has also presented various discussions of the applicability and reliability of numerical simulations, the main tool (but not the only one) to investigate management strategies and the consequences of particular actions [MM, 2002b & PAET 2003b]. The PAET also proposed that a prototype – one-to-one-scale – test should be conducted on the Plaat van Walsoorden to confirm the practicability and effectiveness of the approach proposed.

On March 4th 2002 a Memorandum of Understanding was signed between the Netherlands and Flanders in which a Project Direction Development Scheme Schelde estuary (Projectdirectie ontwikkelingsschets Schelde estuarium – ProSes) was created. ProSes has the task to set up the studies that are necessary to make a strategic environmental impact assessment, an environmental cost-benefit analysis and a nature development plan, a first phase in the implementation of the recommendations made in the LTV project. These studies should be finished in March 2004.

On July 4th 2002 a meeting was held in Borgerhout. Mr Claessens (ProSes) formulated the objective in the "Walsoorden"-project – included in the study programme funded by ProSes – that has to be attained within one year as "is the methodology of deposition or dumping of dredged material within the estuary, such as proposed by the PAET, feasible or not?" [MM, 2002a].

In August 2002 Flanders Hydraulics presented their research programme for the Walsoorden-project to ProSes [FHL, 2002b]. This included a field measurement campaign with floats, the use of the physical scale model for both hydrodynamic and moving sediment tests and the use of a numerical model for hydrodynamic simulations. This proposal did not include sediment transport measurements, despite the fact that the PAET has always stressed the need for such measurements to be able to answer the feasibility question [PAET, 2001b]. The PAET pointed out that the research work had to be finished at the end of April 2003 to be able to analyse the results and to answer the feasibility question before the end of June 2003 as initially requested by ProSes. Due to budgetary constraints within ProSes, the sediment measurement campaign, which is absolutely necessary to the PAET, could not take place before the beginning of June 2003.

The research programme included field investigations as well as both numerical and physical scale model tests. The hydrodynamic part of the research has almost been completed and it has been reported. On sediment transport, a number of aspects of the study, indicated by the PAET as being essential, have not been undertaken. However, with the partial information gathered so far, the PAET may formulate an answer to the feasibility question, bearing in mind that the only way to confirm or contradict the feasibility of steering the morphology by a new dumping strategy would be a real-life test. ProSes agreed, on the basis of a preliminary report by the PAET delivered on July 31, 2003, that this thoroughly monitored test would take place, most likely in spring 2004.

1.2. Description of the test site

The PAET proposed that trials of the proposed strategy should take place at the Plaat van Walsoorden. It is situated in the middle of the reach Hansweert – Bath (Figure 1). The site fulfils many of the requirements in that it has suffered adverse morphological change with accompanying ecological degradation, which are caused by natural development and human interference. It should be noticed that several areas were identified in the Schelde estuary with similar negative evolutions, where the strategy proposed by the PAET could be implemented.

The test area has the characteristic inter-fingering morphology of flood and ebb dominant channels. Some areas remain dry even on spring tides.

The tidal range conditions at the site, compared to those used in the various studies, are as follows:

HANSWEERT	Date	HW [m NAP]	LW [m NAP]	Amplitude [m]
Nasner Neap	02/10/2002	1.61	-1.54	3.15
Nasner Spring	07/10/2002	2.97	-2.66	5.63
Sediment	03/06/2003	2.57/2.51	-2.00/-2.20	4.57/4.71
Scale model	-	2.63	-2.27	4.90
Numerical model	12/06/2002	2.63/2.79	-2.15/-2.26	4.78/5.05

WALSOORDEN	Date	HW [m NAP]	LW [m NAP]	Amplitude [m]
Nasner Neap	02/10/2002	1.70	-1.58	3.28
Nasner Spring	07/10/2002	3.12	-2.70	5.82
Sediment	03/06/2003	2.70	-2.03	4.73
Scale model	-	-	-	-
Numerical model	12/06/2002	2.75/2.91	-2.17/-2.28	4.92/5.19

To date, all Walsoorden studies – field measurements, scale modelling and numerical modelling – have not been undertaken on identical tidal ranges.

2. Work so far completed or in progress

The note [*PAET, 2002b*] presented the various actions recommended by the PAET. The following have either been completed or are still in progress:

2.1. Field surveys

2.1.1. Observation of flow streamlines with drifter floats tracked by satellite

These observations, recommended by the PAET, were taken up in the study at Flanders Hydraulics Laboratory and funded by ProSes. The surveys were undertaken in September-October 2002 by a team of Prof. Nasner (Institut für Wasserbau, Bremen) and reported in February 2003 [*Nasner, 2003*].

During each sequence, five floats with drogues at different depths (0.8 m, 2 m and 5 m) were released simultaneously in cross-sections and tracked during a period usually between one and two hours, providing a “Lagrangean” view of the flow. Using the intermediate positions, almost local “Eulerean” velocities can be deduced.

The flow patterns resulting from this campaign have been analysed. These data have also been used for comparison with the results from physical model tests and numerical simulations.

2.1.2. Sediment transport surveys

In the report on the scale modelling the PAET suggested 12 locations in the Walsoorden area in which the mobility of sediment should be investigated [*PAET, 2002a]*. In the chapter on “Field Surveys” of its Research Plan [*FHL, 2002a*], Flanders Hydraulics mentions that while float track measurements could be contracted, the PAET Team Leader could take care of the bedload measurements. It also mentions a real-life test dumping to be monitored with sediment transport measurements.

A limited sediment transport survey was finally organised in June 2003, outside the memorandum between Flanders Hydraulics and ProSes. It was entirely funded by the Flemish Ministry of Infrastructure and executed with the assistance of the PAET and the Hydraulic Laboratory of the Walloon Region, which made available the instruments for measuring bedload. The surveys were reduced to a measurement, in 3 locations, of flow and sediment transport, with two survey vessels from the Dutch Rijkswaterstaat (RWS) and one survey vessel from the Flemish Maritime Access (MA). The main aim was to demonstrate the feasibility of such surveys and the appropriateness of the Delft Bottle (DB12), a sand transport-rate sampler.

Most of the field measurements have been processed but only part (25%) of the sediment size analysis on the samples (about 260) is completed. This particle analysis was performed with the Visual Accumulation Tube Size Analyser (VATSA), which was available in Flanders Hydraulics but needed to be reconditioned. Only the samples taken during the flood phase were analysed, where the small sample size requires special technology. Contacts were established with a commercial company to test a special particle size analyser (laser technology), so that sediment size distribution could be determined on all the samples.

Besides the Delft Bottle sampler to measure sand transport rates close to the bottom, the Acoustic Sand Transport Meter (ASTM) of Rijkswaterstaat was used on all three

vessels. Flow velocities were measured with ADCP on the two RWS survey vessels, with current propeller meter on the MA survey vessel.

2.2. Scale model tests

A well-tested and calibrated physical scale model (fixed bed) of the relevant part of the Schelde estuary is available in Flanders Hydraulics. It was rebuilt some ten years ago with the bathymetry of 1990. The model covers the area of the Walsoorden test-site and it could be made operational at short notice and at little cost. The model scales are appropriate for fixed-bed tests but the distortion factor of 4 is quite high and not appropriate for mobile-bed tests.

2.2.1. Hydrodynamics

Flow patterns were visualised with floats tracked by cameras (still cameras and video cameras). The technology is described in a draft report [*FHL, 2003*] annexed to this note. These data are extremely valuable for the study, because they give a dense coverage of local surface velocity vectors ("Eulerian" reference) for a single spring tide. Some floats were tracked during longer periods ("Lagrangian" reference).

Differences between field data and model data have initially been investigated for the specific tidal amplitude used in the scale model simulations.

2.2.2. Sediment transport

Preliminary tests made with 3 different lightweight bed materials available in FHL have shown that none was really able to satisfy the scale laws for the model. A suitable material has now been sourced and delivery is imminent. Tests about the sediment movement are expected during October 2003.

2.3. Numerical simulations

2.3.1. Hydrodynamics

An overall hydrodynamic simulation of the Schelde estuary has been created using the SIMONA and Delft3D software. The Delft3D software was available at the start of this project, while the acquisition of the SIMONA software was achieved at the end of 2002. Both SIMONA and Delft3D are three-dimensional modelling systems that allow for a two-dimensional option.

Three Numerical Simulation tools have been created for this project.

The model built within SIMONA covers most of the estuary. This global 2D model has been calibrated on water levels and salinity. So far it has been used only to define the boundary conditions for two other models.

The second of the numerical simulation models is a 2D depth-integrated model that covers a restricted area of interest (Walsoorden area). It uses Delft3D software with a 2D option and its results are depth-averaged as far as the velocities are concerned.

The third of the numerical simulation models is a 3D model that covers the same restricted area as the second (2D) model. The 3D model uses the same Delft3D software but this time with the 3D option: there are 5 layers of computation in the vertical direction between free surface and the bottom, i.e. at every computational

point in the 2D horizontal plane velocities are computed at 5 depths. A number of tests have been and are being currently carried out with 3D hydrodynamics model in order to test the influence of refinements such as: increase the number of layers from 5 to 10, refine the horizontal resolution of computational grid, change values of eddy viscosity. For 2D model of the area computations have been run with halved time-step and various values of eddy viscosity.

It has so far not proved possible to carry out scale or numerical simulations for exactly the same forcing conditions (tide) as were prevailing during the field surveys. Thus the tides used as forcing conditions for the simulations have been chosen as near as possible to the forcing conditions existing during float measurements, but there are dissimilarities that may induce differences between the in situ observed and the computed or scale-model results.

Only hydrodynamic computations have been carried out. The flow patterns produced by the models can be compared with the corresponding patterns from the float measurements. If these patterns are reproduced correctly in the model, the model can be used to fill in the gaps (varying tidal conditions) where no field data is available.

2.3.2. Sediment transport

In the present stage of the study, sediment transport calculations have not yet been undertaken. Clarifications about the Delft3D software will be required before starting completing the local detailed hydrodynamic modelling and starting sediment transport modelling. The existing restrictions on undertaking this work are discussed in Section 3.4.2. No simulations of tracers or sediment transport have yet been attempted.

3. First assessment of feasibility studies

3.1. Preliminary comments about the study tools

The PAET has stated from the beginning of the Walsoorden project proposal [*PAET, 2001b & PAET, 2002b*] that field measurements and physical and numerical models needed to be combined, as each of these study tools has advantages and limitations. They must be seen as complementary tools for the assessment of the alternative dredging strategy.

3.1.1. The fieldwork

Field surveys are not to be seen as collecting data for feeding models, but as a tool to investigate in situ the phenomena which should be represented in the models. They are absolutely indispensable to the overall process of investigations. The field programme was specified to include flow, sediment transport and morphology observations.

- Field measurements are the only tool to investigate the phenomena in situ.
- The field surveys require significant amount of resources and are dependent on the prevailing tidal conditions and the weather.
- Modern positioning systems (DGPS) have become extremely precise. When including “Real Time Kinematic” corrections the observations are released from the heightening errors introduced by referencing measurements to the water surface vulnerable to undocumented water surface slopes. This allows the determination of local water surface slopes, which are significant to assessment of the numerical simulations.
- Determination of velocity structure (distribution in space and time) has become easy with ADCP. However it still needs to be checked with traditional technology (propeller current meter). It is not yet clear how the grading of the sediment may affect the data. The instrument does not measure directly the flow velocity, but by Doppler the effect velocity of reflectors (particles or bubbles).
- Sediment transport measurements are feasible, though difficult to perform, especially for bedload and near-bed transport. The sand fraction in the sediment is the most relevant for morphological studies. Technology is available to measure its movement: Acoustic Sand Transport Meter (ASTM), the Delft Bottle (DB12) and the Bedload Transport Meter Arnhem (BTMA). These last two techniques combine the measurement of the sediment transport rate with the sampling of the transported sediment, so that the sediment size distribution can be determined.
- The paths followed by bottom sediments may be established by tracking marked sediments. They could be obtained from monitoring a real-life disposal test, which unfortunately was not included in the study programme.
- Bottom mapping has become very accurate (multibeam) and provides easy-to-interpret data very quickly. The data are generally processed in real time thereby yielding crucial information on the response of the substrate to hydrodynamic forcing.

3.1.2. The reduced-scale model

- As previously mentioned, the FHL scale model has been constructed for other studies, using the 1990 bathymetry of the Westerschelde.

- The model covers the river upstream from a boundary located between Hansweert and Terneuzen, encompassing the Walsoorden test-area.
- The test area of Walsoorden is quite close to the model's seaward boundary
- Tests are performed with constant tidal conditions; however, other tides can be reproduced if needed.
- The scale model is an appropriate tool to investigate the overall and the large-scale secondary flow patterns as they are determined by the geometry.
- Mobile-bed material available in FHL (polystyrene of 2.45 mm, Bakelite of 0.85 mm and nacre of 0.42 mm) is not well suited for the scale conditions of the model and other, better suited material will be utilised to reproduce the movement of the bed material on the fixed bed. (Polystyrene of ± 0.5 mm).
- The orientation tests about sediment paths showed that simulation with that appropriate sediment would provide sufficient insight on the movement of particles in relation to the morphological features, a major output for the study.
- In the area of the dumping tests, the roughness elements (relatively large cement blocs) were removed because they produced large vortices, not similar to the turbulent flow structure observed in the field.
- The distortion factor of 4 induces limited scale effects for the flow, which are however acceptable when studying the overall flow patterns, but they will have to be taken into account when interpreting sediment transport simulations (particles on fixed-bed).

3.1.3. The numerical simulation models

- The numerical models were built with a bottom topography corresponding to the 2001 situation and any tide can be injected; the simulations are made with a tide similar to the one used in the scale model.
- The combination of several models (SIMONA in 2D for the whole estuary; Delft3D in 2D and 3D for the Walsoorden test-site) is convenient for getting reliable tidal data (vertical and horizontal).
- The Delft3D numerical models are quite recent and have to be tested thoroughly, especially the sediment transport formulae and the way their input variables are calculated.
- The simulation of sediment transport and morphology is possible but has to be checked; this requires good field data.
- Bank erosion cannot be modelled properly with the available tools. It is however a key factor in the morphological behaviour of rivers. This must be seen as a limitation of the present models.

3.2. Outcome of the studies with the different tools

3.2.1. Hydrodynamics

The general flow pattern in the Walsoorden test-area was studied with all three tools: float tracks in the field (Nasner), in the scale model (FHL) and with numerical simulations (FHL, SIMONA in 2D & Delft3D in 2D and 3D versions)

3.2.1.1. Field surveys

The float tracking was chosen to provide clear indications of the patterns of streamlines with which to assess the performance of the physical and numerical simulations. It also provided indications of the speed of water particles along the streamline. It has proved most successful and useful.

The final report issued by Prof. Nasner in February 2003 [*Nasner, 2003*] gives all the details of the technology used and its implementation on the Walsoorden test-site. It should be noticed that during the float tracking, the flow intensity changes. The overall pattern during the flood phase (however with different tidal amplitudes) can be seen on Figure 2, while those of the ebb phase is shown on Figure 3.

3.2.1.2. Scale model

The physical model has been used to compare the flow patterns in the model with the float surveys. The results from these have been reported [*FHL, 2003*] and will be used to assess the possible dispersal of simulated sediments. All these data from the scale model must be seen as indicative, because the geometry of the river is from 1990, during which the flood channel Schaar van Valkenisse was less developed than in 2002/2003.

3.2.1.3. Numerical model

The simulations performed so far are described in a draft report [*FHL, 2003*]. Similarly to the scale model tests, velocity vectors and flow tracks were calculated. These were then compared with the data collected during the float measuring campaign. Where the differences between the field measurements and the 2D simulated results were rather large, a 3D model was set up to achieve a better reproducibility. Further refinements have been executed. It is interesting to note the differences between the results of various options of 3D models: change of grid, of number of layers, etc.

It has been observed that during some phases of the flood the results are really different in the neighbourhood of the tip of Walsoorden plate, especially when the vertical distribution of horizontal velocity directions is considered. The same can be said about over the horizontal velocity direction when depth-averaged. This may be very important for planning of the disposal of dredged material and for the monitoring of its fate.

3.2.2. Sediment Transport

Sediment transport was studied in the field only. In the scale model, only some orientation tests with the available mobile bed materials were executed. Numerical simulation of sediment transport was not foreseen in the original research plan and no simulations of sediment transport have been performed so far

3.2.2.1. Field surveys

The sediment transport measurements were made in the area a priori selected by the PAET for executing the test dumping. Both the ASTM as the DB12 were used to investigate sand transport at the tip of the Walsoorden plate.

The measuring positions were determined from the results of the float campaign and selected among the 12 proposed by the PAET for sediment measurements. This campaign revealed a zone where the velocities were low during the ebb, while they were higher during the flood. A first series of preliminary field measurements were made in three positions in front of the eroded tip of the Walsoorden sandbar (Figure 4). The Delft Bottle (DB12) was used for direct sampling of the near-bed sand transport-rate, at 5 elevations: 0.1 m, 0.2 m, 0.3 m, 0.4 m, 0.5 m from the bottom. A summary of the data is shown in Figures 5 to 7.

Indirect measurements with the ASTM are analysed and compared with the Delft Bottle data. Figures 8 to 10 show the data for the three measuring points.

The samples taken with the DB12 during the flood period have been analysed using a VATSA in order to determine the sediment size distribution. During the ebb period the sediment transport rates are extremely low and many samples are too small to be analysed with the VATSA.

Multibeam surveys were specified as an appropriate means of quantitative assessment of the character of the substrate, the general morphology of the bed, the distribution of meso- and micro-relief and the patterns and amplitudes of bedforms. Only a limited test was performed, offered by a survey company (see annexed map, by EUROSENSE-BELFOTOP N.V.).

3.2.2.2. Scale model

The research plan included scale model test with movable material. Because the bed materials available at FHL didn't comply with the scaling laws, polystyrene with an average size of 0.5 mm was ordered at ICO Polymers (UK) in August 2003. Only an orientation test was performed with a sample of this material (Figure 18)

3.2.2.3. Numerical model

No numerical simulations with sediment transport were foreseen in the study agreement between FHL and ProSes. If the results from the hydrodynamic numerical simulations are satisfactory, attempts of numerical modelling of sediment transport should be included in the future research plan.

3.3. Discussion of the study results

3.3.1. In-situ flow surveys

Although the floats are not distributed over the entire area of interest, the high quality of the data collected by Prof. Nasner and his team (who were recommended by the PAET) allows an analysis of the flow patterns in relation to the local morphology at different tidal stages and for different tidal amplitudes,

The data are analysed per time window as follows (numbers of annexes refer to Nasner's report):

a. Beginning of the ebb phase (HW + ±0.5h till HW + ±3h) with annexes 11, 15 and 31.
b. Middle of the ebb phase (HW + ±3h till HW + ±4.5h) with annexes 12, 16 and 20.
c. End of the ebb phase and slack low water (HW + ±4h till LW + ±1h) with annexes 1, 13, 17, 21, 22 and 25.
d. Slack low water and beginning of the flood (LW + ±1h till LW + ±2.5) with annexes 2, 6, 14, 23, 26 and 27.
e. Middle of the flood phase (LW + ±2.5h till LW + ±4h) with annexes 3, 6, 7, 8 and 28.
f. Flood phase, highest velocities (LW + ±4 till LW + ±5h) with annexes 4, 9, 18 and 29.

g. End of the flood phase (LW + ±5 till HW + ±0.5h) with annexes 5, 10, 19, 24 and 30.

It should be mentioned that names on figures might mislead the reader; an example is the name “Platen van Valkenisse” on Nasner’s annexes; this is a group of sandbars of which Walsoorden sandbar is a part.

A general trend is visible when analysing the float tracks in relation to the following morphological features (names replaced by 3 letters for sake of simplicity, Figure 4):

- MEC: Main ebb channel (Zuidergat)
- MFC: Main flood channel (Schaar van Valkenisse)
- WSB: Walsoorden sandbar
- ETW: Eroded tip of Walsoorden sandbar (seaward tip)
- SSS: Southern sand spit (also called hereafter “sand arrow”, between the tip of Walsoorden sandbar and the main ebb channel (Zuidergat))
- NSS: Northern sand spit (between the tip of Walsoorden sandbar and the main flood channel (Schaar van Valkenisse))
- MSF: Minor Southern flood channel (between the tip of Walsoorden sandbar and the Southern sand spit)
- MNF: Minor Northern flood channel (between the tip of Walsoorden sandbar and the Northern sand spit)

The results of a preliminary analysis on the float tracks are:

a. During the initial phase of the ebb, the near surface and the near-bottom floats in the MFC follow the thalweg’s direction, except for the near-surface ones along the NSS, which have the tendency to cross it towards the MNF. Floats in the MEC released along the WSB cross the SSS, following the general direction of the axis between left bank and WSB high bank. Floats released on the higher part of ETW tend to join the MSF.
b. During the initial phase of the ebb, the general trend seen during the beginning of ebb remains. Floats released in the MFC along the sandbar maintain the same tendency, with flow “spilling” from the MFC over the NSS towards the MNF.
c. During the end of the ebb phase, the flow in the MFC is following the thalweg, with the near-bottom flow slowed down because of the density stratification. At slack low water, near-surface currents are deviated towards the North, except for those following the edge of NSS, some “spilling” over the spit or moving around it towards the South. The floats released along the southern bank of the Walsoorden sandbar follow the same trend as for the previous phase of the ebb, but at about slack low water, the floats at the ETW return along the same path, while those ending at the seaward end of MNF turn North towards the MFC. The situation with low tidal amplitude (Annex 21) needs more analysis, because it shows that flow coming at the end of the ebb from MFC and MNF join the flow of the MEC.
d. During the first phase of the flood, a peculiar situation occurs in the region downstream of the ETW, where the flow heads northwards before entering into the MFC, more the near-surface flow than the lower one. After this initial situation, the flow in the MFC follows roughly the overall direction of that channel, except that the flow closest to the NSS seem to spread over the edge at the landwards part, where it connects to the Walsoorden sandbar. The flow in the MSF passes transversally over the SSS.

e. In the middle of the flood phase, before the highest flood velocities, it seems that the zone of the MNF, between NSS and ETW, acts like a dead zone, so that the flow divides between the MFC and MEC+MSF, spilling over the SSS.
f. With the highest flood velocities, the “dead zone” effect in the MNF reduces and the flow is divided by the ETW. Flow in the MNF spills over the NSS towards the MFC, mainly in the area where it connects to the Walsoorden sandbar. The effect of density stratification is visible, mainly in the MFC.
g. At the end of the flood phase, some flow is oriented towards the ETW, flowing over the WSB. The flow in the MFC has similar direction as during the previous phase of the flood, and so is the case for the flow in the MEC+MSF, spilling over the SSS.

The preliminary analysis is based primarily of the shape of the float tracks and more detailed work has to be done taking into account the flow intensities.

3.3.2. In-situ sediment transport surveys

The surveys recommended by the PAET had not been included in the study programme of the contract between Flanders Hydraulics and ProSes. However, thanks to funding by the Flemish administration, the field campaign of June 3rd 2003, could be executed. It was a preliminary test designed to demonstrate the effectiveness of the specified techniques and operational procedures and to get a first idea about the sediment transport processes. It is quite unfortunate that detailed topo-bathymetric (multibeam) surveys could not be executed prior to or during the observations, so that the context of the measuring rigs in relation to bedforms was unknown. Interpretation is therefore more difficult. The delay in particle size analysis is hampering full interpretation of the results for sand transport. However, the limited survey has given enough evidences that support the opinion of the PAET about need for further field campaigns.

The morphological characteristics of the site are revealed by the multibeam survey results (Annex Maps). The area is characterised by a transition from relatively low amplitude bedforms in the deeper site (Kaloo) to well developed bedforms at the shallow site (Scaldis). Although carried out 3 weeks after the sediment transport observations, the multibeam survey is considered representative of circumstances at the time of the measurements. The expected presence of bedforms of this type was the reason for the specified inclusion of the pre-observation multibeam survey. It is worth noting that the location of measuring points with respect to the bedforms is likely to have a significant influence on the measured transport rates and on the nature of the moving sediment sampled.

Comparison of the DB12 data with the ASTM data (Figures 8 to 10) shows that the trend in the DB12 results is less erratic. This is explained by the fact that sand movement is spatially and temporally variable but the DB12 integrates over five minutes, providing an average value, while the ASTM data are integrating over a shorter time giving greater variability.

The results of both DB12 direct sampling and ASTM indirect measurements show that in all three positions MP1, MP2 and MP3 (Figures 5 to 7; times 7u - 13u), the near-bed sediment movement is very weak during the ebb. In the first phase of the flood, this near-bed sediment movement is still weak, though somewhat higher. Stronger sand transport rates are observed when flood flow intensity is highest (HW–1h ~ 17u).

Both DB12 and ASTM data show that the transport rate during the flood is the lowest at MP3. At the start of the flood, higher transport rates are observed in MP1, but the difference with MP2 is very small. In contrast, the highest rates during the maximum flood occur in MP2. The peak in MP2 at 16u45 could probably be due to an erroneous sampling: the inlet of the DB12 may have scooped the bottom (in a dune?); this could explain the very large transport rate. This explanation seems realistic, as the sediment size of the sample taken at 10 cm from the bottom is the similar to the one of the bed material. It should have been smaller, as for all other Delft Bottle samples. Another explanation, though less likely, is the existence of a plume of bottom sediment created by a local disturbance of the flow (such as by a vessel passing by).

The size characteristics of the moving sediment (Figures 11 to 13) indicate that the mobile sediment represents a subset of the bed sediment, as would be expected. Part of the future work in designing the placement exercise will be based on a detailed comparison of the sediments at the site with the sediments to be dredged.

Sediment size analysis could not yet be performed on all sediment samples. Further analysis will be needed. Also the quality of the data need to be checked, comparing transport rates and particle sizes. The first analysis shows that the data of MP1 (Kaloo) and MP3 (Scaldis) are consistent with each other, the transport rates being lower for MP3, closer to the Walsoorden sandbar. The data from MP2 (Veremans) are not so consistent (more erratic) and this needs therefore to be checked further. The ASTM and DB12 data are in general both higher in MP2 than in MP1 and MP3. It should be mentioned that the relative position of the 3 vessels observed in the field seemed different from the one given in the instructions (MP2 more to the North from an alignment connecting MP1 with MP3.

A first conclusion is that for the tidal conditions observed, sediment is moving predominantly to the sandbar during the flood, while ebb transport is very weak. The comparison map [*RIKZ, 2001*] indicates that the area where the measurements were performed had been eroding between 1985 and 2000. The differences between 1997 and 2000 are not pronounced (patchwork of erosion and sedimentation), but that the higher part of the sandbar (position East of the MP3 Scaldis, the higher part of the sandbar) has been clearly eroding. The morphological evolution of the Walsoorden sandbar needs to be analysed in more detail with maps over the past two decades.

3.3.3. Scale model

The results of the simulations so far undertaken are described in the FLH draft report [*FHL, 2003*] which shows the results of the physical and numerical modelling. They relate only to hydrodynamic simulations.

The general pattern of flow tracks and velocities obtained from the surveys conforms to what members of the PAET expected on the basis of their field experience. Isovel lines were deduced from the surface velocities measured in the reduced model with the spring tide used for the tests [*FHL, 2003*]

Figures 14 and 15 give a view of the isovel areas with one-hour interval. The situation at HW-5h corresponds roughly with slack low water and HW+1h with slack high water. Though more detailed analysis is needed at this stage, it seems that the intensities observed in the model correspond well with the field data. During the start of the flood phase, lower velocities are visible in the area between the northern sand spit (NSS) and the eroded tip of Walsoorden sandbar (ETW). It is only during the last phase of the flood (when velocities are highest) that the flow accelerates in the minor

Northern flood channel (MNF). During the ebb, velocities in this area are again smaller than in the main flood and ebb channels (MFC & MEC). More details are given in the FHL draft report.

3.3.4. Numerical simulations

Figures 16 and 17 present the evolution of the isovel lines, similarly to what was done for the scale model. The overall picture is the same. However, differences can be observed in places that are quite important for the study. One of these places is the connection between NSS and WSB, where the flood flow does not seem to accelerate in the numerical model. This acceleration, measured in the field, is visible in the scale model results. More detailed analysis is thus required and will be presented in the final report.

3.4. Discussion of the investigative tools

The Walsoorden study confirmed the need for combining field surveys and studies with numerical and physical scale modelling. From the experience gained so far, lessons can be learned, which are summarised below.

3.4.1. Field measurements

The flow and its structure can be investigated with several means. The ADCP has become a standard apparatus allowing determining discharges and instantaneous velocity profiles, as well as the turbulent structure of the local flow (Eulerean). However, it is still uncertain whether the velocity of the solid particles measured by Doppler effect always correspond to the flow velocity, especially in the layers close to the bottom. For this reason, the PAET recommends continuing using also other means to determine the structure of the flow, especially for the velocity profile close to the bottom.

Satellite tracked floats, with drogues at different depths, provide valuable information on the flow paths (Lagrangean), indispensable for verifying the model results.

Morphological changes in the Westerschelde are mainly due to sand transport processes, the silt and clay fractions having less impact. For measuring sand transport, the DB12 proved to be a reliable and useful sampler. It measures directly the transport rates averaged over a time lapse larger than that of the turbulent fluctuations. The DB12 requires neither calibration nor laboratory analysis for determining the transport rates. The samples are usually large enough for a sediment particle size analysis. The ASTM, in the version used by MID Vlissingen, requires calibration with pumped samples. The data are not averaged values as for the DB12. Samples are too small for particle size analysis. It was not possible to check whether ADCP backscatter data could yield valuable information on the spatial sediment distribution. This technology was tested in other rivers and it would be good to check this in the future.

The test made on 25 and 26 June 2003 shows that the geometry of the river can be mapped with high accuracy with multibeam survey equipment, combined with DGPS positioning and other means to get the correct altitudes, without needing referencing to terrestrial base stations (except for DGPS). Though the data were not processed yet in the Walsoorden project, DGPS altitude measurements allow determination of local slopes with sufficient accuracy. The changes in slope are useful when analysing morphological changes, thus also when assessing the impact of river works.

Though LIDAR topographic surveys were not yet applied on the test site, this technology should be used in combination with multibeam bathymetric surveys to generate the accurate topo-bathymetric maps.

3.4.2. Modelling Tools

As far as hydrodynamics is concerned, it can be said that the comparisons between the results observed in scale model and those computed on one hand, and with the measurements on the other hand are rather encouraging. The results indicate to date that the overall flow patterns are quite well reproduced, though differences were found, mainly during the slack low water and early flood period.

This positive statement does not mean that the numerical simulation models are in any way "validated" or "calibrated" and that from now on they can be used and trusted for all purposes. More specifically, in our opinion they should not be used, without precaution or limitation, as an operational tool to study the alternative dumping strategy at Walsoorden.

From the point of view of the study, one should consider at this stage three essential questions:

(i) On the bases of results obtained, can we trust the tools in the domain of hydrodynamics (free surface elevations, velocity fields)?
(ii) Can we, using these hydrodynamic results, give a preliminary answer concerning feasibility of the proposed dumping strategy?
(iii) Are the tools good enough in reproducing hydrodynamics so that they can be used for sediment and morphology studies, to simulate within the area of interest the fate of dumped sediments, to confirm and to refine our opinion concerning the feasibility of the proposed dumping strategy?

Concerning the scale model, it must however be said that since 1990 the flood channel of Valkenisse has deepened. These morphological and other evolutions will probably have an influence on the hydrodynamics. The only way to verify the effect of this change on the hydrodynamics would be to replace the 1990 model geometry with the one of 2001. Despite the bathymetric differences, the hydrodynamic reproduction is quite satisfactory.

Concerning the numerical models, it must be said that while overall (over the area of interest) 2D velocity fields seem to be truthful, there are differences between simulation and reality that must be explained, some of them eliminated and other accepted either as tolerance or as unavoidable inaccuracies. The above-mentioned apparent differences in flood flow pattern at the end of the MNF channel are one of these. The differences are relatively local, limited in time and space, overall tendencies coinciding. The purpose of the modelling, however, does not allow for neglect of the differences, for acceptance of the results as they are and the conclusion that the tools are trustworthy. Indeed, the purpose of the whole project is to predict local behaviour of the dumped sediments, their deposition, movements and erosion. Thus one would like the models to predict local variation of the currents. Since there are local differences between observed and modelled currents one has to try understand their causes.

For the numerical simulations, specific comments can be made. The first category of differences relates to discretisation, numerical approximations, incomplete or inadequate representation of bed topography, etc. Usually it is possible to improve

the situation (e.g. through higher resolution of computational grid, decrease in computational time step, correction of erroneous boundary conditions) or at least to obtain good idea about the consequences of the inaccuracies. For example, one aspect that deserves attention in a later analysis is the fact that the float tracks in the numerical model follow rather well the computational grid lines.

Second category of differences is such that we have to live with them because improvement is impossible. For instance, reasons such as:

- costs and delays (increase in resolution of computational grid, reduction in time step duration, new scale model with present bathymetry and less distortion) that are prohibitive as compared with the purpose of the study or expected improvements;
- impossibility to represent with available tools some of the relevant physical phenomena to be considered;

Here improvement of the situation is not possible but the methodology of analysis should take this into account.

Clearly, the study of the reasons for the discrepancies between observed and computed results, ranking them in the above mentioned two categories, asks for time and detailed analysis. Since it is sometimes impossible to find such reasons from the numerical model alone, inspection of results of scale model and their comparison with observed reality, as well as of results of dumping tests could be essential for the conclusions. And for the decision: should numerical model be improved or are the results acceptable for further studies.

The conclusion in relation to the three questions asked above:

a) For the numerical simulations, we can trust the tools in the domain of hydrodynamics (free surface elevations, velocity fields) except for the following points that should be checked, explained and possibly improved:
    - problems related to ADI method of numerical solution,
    - number of layers in 3D model,
    - influence of salinity in 3D model,
    - possible transverse slope inaccuracies in downstream level-imposed boundary condition for 2D and 3D,
    - detailed representation of bottom topography of the area of interest, especially grid resolution and interpolation of bottom heights for each numerical grid point.
b) For the scale model, we can trust the tool in the domain of hydrodynamics, (free surface elevations, velocity fields) except for the following points:
    - secondary flow effects induced by the distortion
    - improper flow resistance of the fixed bed (roughness elements were removed)
    - bottom geometry from 1990
c) We can, using these hydrodynamic results, give a preliminary answer concerning feasibility of the proposed dumping strategy but we cannot base our assessment only on these results. We also have to take into account the fact that some phenomena may never be represented 100% accurately by the tools. They are problems such as:
    - "near field problem": the fate of sediment dumped at a given location. The sediments settle down immediately to the bed or are immediately displaced by currents. They can be eroded later and carried away. Their

cohesion and corresponding resistance to erosion may be greater or smaller, etc
  - covering and uncovering of tidal flats is not simulated in the available software for the purpose of detailed analysis but rather only for the purpose of overall current field simulations. Thus local accuracy is sacrificed to this main goal using as most important criterion the smoothness of the solutions and the elimination of spurious numerical oscillations, wiggles etc. It is possible that an increase in resolution of the grid can solve the problem. But it is also possible that nothing can be done and engineering hypotheses as to what happens must be used.

d) We cannot assess how good the numerical tools are in reproducing morphological changes as a result of erosion, transportation and deposition of sediments. This question can be answered only after the test computations will have been carried out. However, one point is to be stressed immediately: the current number (5) of vertically disposed layers in the 3D model will most likely be insufficient to simulate sediment movement, especially the near-bed transport and the exchange between bed-load and suspended load. It is probable that at least 10 layers would be needed. This is confirmed by the analysis of the velocities measured along the vertical in the 3 positions during the field survey on 3 June 2003.

e) We cannot assess yet how the new mobile bed material may behave well enough to reproduce sediment movement on the fixed-bed scale model However, the test made with a small sample of this new material give quite encouraging results. It should be emphasised that it is quite improbable to run a mobile-bed model for the study purposes.

From the above, one can draw a first idea concerning the sequence of numerical model studies and activities using the tools necessary to complete the preparations for the disposal trials:

- At a preliminary stage, the near-field behaviour of dumped materials must be described (a scenario or scenarios!) using engineering experience and the knowledge of bed topography (morphology) as well as the variation of depth during the tidal cycle at the area of the hypothetical dumping site.
- The further fate of deposited sediments can be very approximately deduced from the velocity fields as supplied by the FHL Report [*FHL, 2003*]. If necessary, intermediate velocity fields can be printed from stored results.
- These two inputs should be then combined with information obtained from field measurements.
- Improvements and refinement of existing models (higher resolution of computational grid, decrease in computational time step, correction of erroneous boundary conditions) should be carried out in parallel.

3.5. Summary about hydrodynamics and sediment transport

The following conclusions may be drawn from the presently available study results:

- The information about the hydrodynamics in the area proposed for the dumping test is sufficient to identify the recommendable dumping site.
- Each of the secondary flood channels MNF and MSF located at each side of the Walsoorden sandbar tip has a different hydrodynamic behaviour.
- The Northern sand spit NSS clearly guides the flow during the well-developed flood and ebb flow. The main flood channel MFC undergoes a significant ebb flow effect along the northern border of the Walsoorden sandbar.

- The Southern sand spit SSS does not guide very much the flow, neither during flood or ebb phases. Nevertheless, it remains in place since long and its existence is likely linked to secondary flow structure and bedload paths.
- Sediment disposed in the area recommended by the PAET will most likely remain in the Northern secondary flood channel (MNF), though part of it might be transported in the main ebb channel (MEC), but staying along the Southern sand spit (SSS).
- The zone recommended for dumping dredged sediment is therefore located in the triangular area between the ETW and the NSS and could be the place to have the test for dumping and monitoring a limited amount of dredged sediments.

4. Present Status of Outstanding Work

4.1. Sediment Transport Observations

The particle size analysis will continue on the remaining sediment samples from the surveys. Further analysis is possible with the data of DB12, ASTM and ADCP.

4.2. Scale Model tests

A series of hydrodynamic simulations with the bathymetry of 1990 are completed and have been reported. Delivery of material suitable for transport simulation is expected in September and simulations of sediment paths will be made. The next phase will be to reconduct the same tests with the new, expected geometry of the sandbar. The modelling results will be used to assess the possible impact of the modified geometry on the overall flow and sediment transport patterns. From these and from further numerical modelling, it would be possible to formulate an expert opinion on the impact the new geometry might have on the dredging efforts needed to maintain or increase the depths on the neighbouring crossings in the navigation route.

4.3. Numerical Simulations

Extensive testing of the numerical modelling tools has led to the present limited and qualified confidence in the generality of hydrodynamic results. Difficulties still persist with the detailed hydrodynamic simulations of the test area and work by Delft Hydraulics on these issues is ongoing. If and when these problems are overcome, 3D hydrodynamic simulations of the target morphology (the morphology it is hoped to achieve by controlled disposal) can be undertaken to compare with the simulations of the present (2002) morphology. If the problems cannot be solved then reliance will have to be placed on the 2D simulations. This situation is not regarded as satisfactory.

At present there are no plans or prospects for numerical simulation of sediment transport or morphological change. This is highly unsatisfactory, as it remains a key component of the investigative process specified by the PAET.

5. Assessment of the feasibility of the alternative strategy

The question posed on July 4th 2002 was: “is the methodology of deposition or dumping of dredged material within the estuary, such as proposed by the PAET, feasible or not?” [*MM, 2002a*].

5.1. Morphological assessment of the Walsoorden test-site

Morphological dredging and morphological engineering has been applied successfully in major rivers, when river works were treating the causes of the evolutions instead of treating the effects: the idea of working with the river instead of working against it. The starting point in this approach is thus a preliminary but thorough morphological assessment, followed by a morphological prediction of the natural changes to be expected, then real-life experiments (the “learning-by-doing”) and a proper monitoring of the morphological impacts of the river works. Basic to this approach is the development of tools for predicting the morphological changes, the natural as well as those produced by the river works.

The area of the minor northern flood channel (MNF) located between the eroded tip of Walsoorden sandbar (ETW) and the northern sand spit (NSS) is likely to be the most suited for dumping sediment in an initial phase of the experiment. This is the area where flow and sediment transport was measured on June 3rd 2003. During the ebb phase and the initial flood phase, most of deposited sediment would remain in place. During the flood, sediment will move towards the sandbar and selective transport may bring the finest particle size fractions on top of the sandbar. During the period of highest flood velocities, part of the deposited sediment might be transported and pass over the place where the NSS is connected to the Walsoorden sandbar. These sediments would then probably be moved by the ebb flow along the NSS, which could extend further in direction of Hansweert. The expected overall result is an accretion of the Walsoorden sandbar tip in direction of Hansweert. The new reconstructed tip of the sandbar should then better divide the flood discharges between the MEC and the MFC.

It must be stressed that the causes for the morphological evolution in the reach between Hansweert and Bath need to be dealt with. This would require a thorough study of the way the hard bordering of the estuary in that region is affecting the morphological processes (changes in geometry of sandbars and channels). Attention should be given particularly to the alignment of the levees and bank revetments, as well as to all the structures protruding into the river, like groynes and harbour entrances.

With the Walsoorden study, a first attempt is made to have the morphological assessment with a preliminary prediction of the further morphological evolution. Based on the outcome of the studies, a new shape of the Walsoorden sandbar expected after dumping dredged material in the Northern secondary flood channel (Figure 19) was drafted. This new shape can now be included in the ongoing environmental impact assessment studies.

5.2. Assessment of the practicability of the alternative strategy

The practicability of the proposed alternative strategy relates to the operational practicability, the ecological and environmental efficacy, and the feasibility of the morphological monitoring. It must be stressed again that the strategy is not specific to the Walsoorden site and can likely be applied in other areas of the Westerschelde.

5.2.1. Operational Practicability.

The proposals presented by the PAET in May 2001 were based on up to date information and experience within the team regarding the technologies, which they knew to be available or thought to be available. Presentations made by dredging contractors to the PAET and ProSes have confirmed that the technology to dispose accurately quantities of sand in controlled thickness over specified areas is available. The equipment, with satellite positioning and computer control, has operated successfully in difficult conditions of waves and tidal currents, significantly more difficult than those likely to be encountered at the test site or elsewhere in the Westerschelde.

5.2.2. Ecological and Environmental Efficacy

The proposed alternative strategy for the disposal of dredged material was developed in the context of the project LTV (Long Term Vision). As such it is viewed by the PAET as one of the key elements in the future management of the Westerschelde to meet part of the objectives of LTV, especially to manage the morphology. It may become a crucial contribution to the LTV objectives of Accessibility, Safety and Ecology because of the key link between morphology and ecology. The need is to reverse the progressive simplification of the morphology and the associated loss of ecological diversity. The proposed strategy can be an effective, much needed tool to develop greater morphological diversity and regenerate key biotopic elements.

On the tip of the Plaat van Walsoorden, the bedform amplitudes are in a range of 0.5 m to 1.5 m, what means that the depth of substrate instability is more than one metre. The preliminary sand transport observations show a consistent relationship between the maxima in current velocity and sand transport during the flood. Sample analyses indicate that the mobile population observed on June 26th was a subset of the bed population and as such the differentiation of sediment sizes necessary for creation of ecological diversity is likely. Sediment supplied to the area is likely to undergo selective transport, resulting in a new and varied sandbar shape with a varied substrate character. The modified velocity patterns over the wide shallow areas are expected to regenerate a more diversified habitat. Presently available data indicates that these objectives are realisable.

It must be clearly understood that the proposed disposal methodology, with its close control and monitoring, is not a once-off operation but would become an important tool for a morphological, and hence ecological, management methodology.

5.2.3. Morphological monitoring

In order to control and monitor the placement of material and to monitor the morphological changes taking place, the PAET recommended the use of multibeam hydrographical surveys and LIDAR as an acceptable method to provide data of suitable quality to the task. The successful demonstration survey, carried out on June 26 [*PAET, 2003d*], confirms that appropriate data could be collected, processed and analysed on a suitable time scale. These kind of surveys would be combined with direct sediment transport and flow velocity measurements, such as during the field surveys conducted on 3 June 2003 [*PAET, 2003c*]. The advantage of this approach is that it would give, almost instantaneous, valuable information on the morphological impact.

Thus any real-life tests of dumping dredged materials and the induced morphological effects can be monitored in near real time. This monitoring will provide the first level of prudent management of the control of the disposal tests and a reliable and meaningful framework of information for parallel ecological impact assessment as previously discussed [*MM, 2003b & MM, 2003d*].

6. Recommendations for further studies and tests

A critical path should be developed aimed at optimising the programme for the design and execution of the full-scale dumping trials. This critical path would include the completion of work and analysis of the physical and numerical modelling exercises as a basis for considering issues related to the dumping experiment. The detailed design of the dumping experiment would include the following elements:

6.1. In situ sediment disposal experiment

6.1.1. Morphological analysis as a basis for "real-life" tests

Existing data and analyses should be evaluated to examine the recent detailed morphological changes in the study area (part of the morphological assessment). This would be supplemented by a topo-bathymetrical survey, combining a multibeam survey with LIDAR, to provide a baseline for subsequent monitoring and a context for the location of detailed sediment transport observations.

6.1.2. Sediment transport network in the experiment area

The data from the morphological survey would also be used to evaluate the contemporary sediment transport network (number of locations where to measure flow and sediment transport) which would be assessed by further multibeam surveys. Where appropriate, limited tracer tests should be made to examine sediment dispersal patterns, information that cannot be gathered with the direct sediment transport measurements.

6.1.3. Detailed sediment transport observations for the design of disposal tests

Essential data are required on the distribution and types of sediment being transported, and the rates of transport, in order to provide an appropriate design for the placement operations. The rates and patterns of placement need to be matched to the patterns of transport. Detailed observations combined with numerical simulation are needed for this exercise, as presented in the note [*PAET, 2002b*]. Analogous information on the sediment to be disposed of is also required.

6.1.4. Detailed design and specification of disposal tests

The total quantities, distributions and rates of sediment placement will need to be specified on the basis of the field and simulation data. This programme should be discussed with possible contractors prior to implementation or tender action.

6.1.5. Disposal trial and monitoring

The sediment quantities defined in the design process will be placed using the equipment and techniques already described to ProSes [*PAET, 2001b & MM, 2003c*] and available with the dredging companies. The distribution and rate of placement of the dredged materials will be defined in the Design of Disposal Tests process (viz. above). The placed material, its dispersal and related morphological changes would be monitored by multibeam and LIDAR surveys. In the monitoring exercise, the emphasis must be on real time data display and rapid (on line) analyses. The data collection and data analysis technology and procedures to undertake appropriate monitoring are already available, in routine use, and do not need development.

6.2. Additional simulation facilities.

An updated physical model and enhanced numerical modelling tools will be required in connection with 6.1.4 of the critical path.

The building of a new scale model could be considered if the outcome of all studies results in a decision to go ahead with the real-life tests. The new scale-model would be based on the most recent topo-bathymetry, and, optimally, have different scales with less distortion and alternative location of its boundaries. Based on the experience gathered with the present model, runs would complement efficiently the conclusions from field measurements and numerical simulations, because it would allow studying the effect on sediment transport patterns of a tentative change in morphology, as could be induced by the alternative dumping strategy. The near-field phenomena are usually better reproduced with scale model, rather than with numerical models, in particular because the phenomena are mainly governed by bed load. The investment must be assessed carefully and depend upon some undecided conclusions on the applicability (and reliability) of the numerical modelling of hydrodynamics and sediment transport.

In parallel with the in situ dumping test it would be interesting to run numerical 3D model that would reproduce real-life observed tide and sediment dumping. This would allow for precise validation of the model and for assessment of its accuracy. Consequently the model could be use to plan and guide dumping procedures while being, from monitoring results, validated on nearly real-time basis.

7. Conclusions and further recommendations

The Port of Antwerp Expert Team has analysed the results from the studies conducted at Flanders Hydraulics Laboratory under the ProSes contract and other relevant information. A number of aspects of the study, indicated by the PAET as being essential, have not yet been undertaken, specifically about sediment transport. Nevertheless, no investigative results so far derived, concerning hydrodynamics or sediment transport, indicate that the placement of material as proposed by the PAET can not be used to influence the estuarial morphology so that degraded areas and their associated biotopes could be regenerated. Field investigations, numerical modelling and scale model tests have given enough evidences to support the PAET opinion that the proposed alternative strategy for dumping dredged material is feasible and likely to reshape the tip of the Walsoorden sandbar as expected. The experts insist on the need of a real-life (in situ) limited dumping test, well documented and thoroughly monitored, for which the necessary technology is readily available.

The analysis of the data has also shown that all investigative tools were needed to reach this conclusion and that morphological assessment of the Westerschelde should not be based only on modelling alone.

In its reports [*PAET 2001a & 2001b*], the PAET has stated that dredging and dumping can and should be used to steer the morphology of the Westerschelde to maintain its dynamic behaviour and ensuring sufficient areas of diversified ecological habitats. The link between morphology and ecology is evident. The steering of the river's morphology should have various objectives, those stated in LTV: improving navigation conditions and maintaining or improving the ecological richness of the estuary, while checking the flood risks.

The "morphological dredging" is recurrent and more appropriate than the "hard" river works such as bank revetments and defences (groynes, spur dykes etc.). Morphological dredging must be based on a careful, preliminary morphological assessment. Its execution must be well monitored, so as to allow corrections in the dredging and dumping programme. This will ensure the reversibility of the works, so that no long-lasting damage might occur.

The PAET insists on the fact that the alternative dumping strategy, a first step towards morphological dredging, can only be a part of the management of the Westerschelde morphology. A thorough study of the hard bordering of the estuary, the history of river works and the assessment of the impact of these works, is needed to treat the causes of unwanted morphological evolutions.

Regarding the morphological impact of dredging operations in the Westerschelde, the PAET hopes that its approach can help bringing more clarity in this complex matter. The PAET insists also on the fact that the alternative strategy to dispose dredged material is needed to steer the river's morphology for the present maintenance dredging, even without a further deepening of the navigation route.

The alternative strategy for dumping dredged material can and should be tried on Walsoorden, but also on other sites where unwanted morphological changes are observed. This would not necessarily require the same investigations, as the experience gained on one site can be used on another, if the processes are better understood.

A last comment to those who express fears for negative impacts that could be induced by the proposed strategy: who has ever expressed the same reservations when polders were created in the past decades, when bank revetments and protections were built along schorre and slikke, when port structures were built along the river banks?

8. References

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9. List of acronyms

ADCP	Acoustic Doppler Current Profiler
ASTM	Acoustic Sand Transport Meter
BTMA	Bedload Transport Meter Arnhem
DB12	Delft Bottle sampler (1 for suspended, 2 for near-bed load)
DGPS	Differential Global Positioning System
ETW	Eroded Tip of Walsoorden sandbar (seaward tip)
FHL	Flanders Hydraulics Laboratory (Borgerhout)
GMT	Greenwich Mean Time
HW	High Water
LIDAR	Light Detection and Ranging (an Airborne laser scanning terrain modelling system)
LTV	Long Term Vision
LW	Low Water
MA	Maritime Access, Flemish Government
MEC	Main ebb channel (Zuidergat)
MFC	Main flood channel (Schaar van Valkenisse)
MID	Meetinformatiedienst (RWS)
MM	Minutes of Meetings in the Walsoorden project (by PAET)
MNF	Minor Northern flood channel (between the tip of Walsoorden sandbar and the Northern sand spit)
MP	Measuring Point (of survey vessels)
MSF	Minor Southern flood channel (between the tip of Walsoorden sandbar and the Southern sand spit)
NAP	Nieuw Amsterdams Peil
NSS	Northern Sand Spit (between the tip of Walsoorden sandbar and the main flood channel Schaar van Valkenisse)
PAET	Port of Antwerp Expert Team
ProSes	Project Directie Ontwikkelingsschets Schelde-estuarium
RIKZ	Rijksinstituut voor Kust en Zee
RWS	Rijkswaterstaat
SSS	Southern sand spit (between the tip of Walsoorden sandbar and the main ebb channel Zuidergat)
UIA	Universitaire Instelling Antwerpen (University of Antwerp)
VATSA	Visual Accumulation Tube Sediment Analyser
WSB	Walsoorden sandbar