Sediment relocation to shallow water near Walsoorden sandbar

Alternative relocation strategy Westerschelde Relocation test Walsoorden. Final evaluation of relocation test 2006

Vos, G.; Plancke, Y.; Ides, S.; De Mulder, T.; Mostaert, F.

September 2009

English translation, November 2012

WL2009R754_03b_rev5_0_EN

This publication must be cited as follows:

Vos, G.; Plancke, Y.; Ides, S.; De Mulder, T.; Mostaert, F. (2009). Sediment relocation to shallow water near Walsoorden sandbar. Alternative relocation strategy Westerschelde Relocation test Walsoorden. Final evaluation of relocation test 2006. WL Rapporten, 754_03b. Waterbouwkundig Laboratorium: Antwerp, Belgium

flanders
HYDRAULICS RESEARCH

Waterbouwkundig Laboratorium

Flanders Hydraulics Research

Berchemlei 115
B-2140 Antwerp
Tel. +32 (0)3 224 60 35
Fax +32 (0)3 224 60 36
E-mail: waterbouwkundiglabo@vlaanderen.be
www.watlab.be

EFQM
Committed to excellence

Document identification

Title:	Sediment relocation to shallow water near Walsoorden sandbar: Alternative relocation strategy Westerschelde Relocation test Walsoorden. Final evaluation of relocation test 2006		
Commissioning body:	Waterbouwkundig Laboratorium	Ref.:	WL2009R754_03b_rev5_0_EN_EN
Key words (3-5):	Westerschelde, Walsoorden sandbar, relocation test, morphology, ecology		
Text (p.):	52	Tables (p.):	/
Appendices (p.):	11	Figures (p.):	/

Confidential:	☐ Yes	Exception:	☐ Commissioning party
			☐ Internal
			☐ Government of Flanders
		Released from	
	☒ No		☐ Available online

Approval

Author	Reviser	Project leader	Department head
Gwendy Vos Msc. Ir. Yves Plancke	ir. Stefaan Ides	ir. Stefaan Ides	Dr. Frank Mostaert

Revisions

No.	Date	Description	Author
1_0	16/05/2008	Draft report	Vos, G.
1_1	30/05/2008	Comments quality control	Ides, S.; Plancke, Y.
2_0	03/10/2008	Supplemented draft report	Vos, G.
2_1	15/01/2009	Comments quality control	Ides, S.; Plancke, Y.
3_0	31/01/2009	Final draft report	Vos, G.; Plancke, Y.
3_1	24/03/2009	Revision	Ides, S.
4_0	11/05/2009	Draft final report	Vos, G.; Plancke, Y.
4_1	07/07/2009	Commissioning body's comments	Roose, F.
5_0	17/09/2009	Definitive final report	Vos, G.; Plancke, Y.
6_0	04/05/2011	Translated final report	
6_1	22/06/2011	Revised translation	Vos, G.; Plancke, Y.
6_2	16/05/2012	Revised translation	Roose, F.
7_0	6/11/2012	Accepted translation final report	Vos, G.; Plancke, Y.

Abstract

In 2001, an independent team of experts (PAET) formulated the idea of disposing of dredged material outside the traditional relocation sites. As part of the morphological management process of the Scheldt estuary, the relocation of dredged material could make a proactive contribution towards the realisation of the aims formulated for the estuary. As a pilot project within this morphological management process, it was suggested that dredged material be applied to the seaward tip of the Walsoorden sandbar.

In 2002-2003, Flanders Hydraulics Research investigated the feasibility of the proposed idea. The results of the on-site measurements and numeric and physical model trials did not contradict feasibility. A definitive answer, however, would only be possible after the execution of an in situ relocation test. This test was conducted in 2004 and involved 500,000 m³ of sand being applied using a diffuser. A comprehensive morphological and ecological monitoring programme followed this test. The results of the test indicated that it was a morphological success and that no negative ecological impact had been established.

In 2006, a second relocation test (comprising 2 phases) was conducted, during which use was made of the traditional relocation technique: dumping ("clapping) . In total, 1,400,000 m³ of sand was deposited along the seaward tip of the Walsoorden sandbar. A very intensive morphological and ecological monitoring programme was, once again, carried out to follow up the impact of the relocation trial. This report sets out and analyses the results of this monitoring.

With regard to morphology, it can be asserted that the disposed material is quite stable but, compared to the test in 2004 which took place closer to the sandbar and also in a less dynamic zone, a greater percentage of material was transported. Some of this transport takes place in the direction of the sandbar which is desirable in order to give the sandbar a new shape. In addition, however, some material was also transported outside this zone. Where this material came to rest has not yet been clearly established. In reference to the development of the Schaar van Waarde/Schaar van Valkenisse secondary channel, it can be concluded that the section was not significantly impacted by the relocation test. It has been established, however, that relocation in the Schaar van Waarde secondary channel has caused a local reduction in the section. To what extent the deposits impacted upon flow patterns cannot be determined.

With regard to ecology, it can be noted that the trends for the various parameters (sediment composition, benthos, height of the sandbar) were not significantly influenced by the new relocation test, both for sub-tidal and inter-tidal areas. There seems to be an increase in coarseness of the bed materials off the relocation site but due to a lack of sufficient data preceding the test period this cannot be verified.

Due to the success of the relocation tests along the Walsoorden sandbar, the future relocation strategy for the expansion of the channel will include relocations at 4 locations along the sandbar edges. Additional research will be carried out in order to optimise the relocation strategy per location as these locations are not all similar. This new relocation strategy combines the relocation of material from dredging work with the creation of ecological potential. This method creates a win-win situation, but it must be noted that other measures can be taken other than relocation in order to use morphological management to proactively fulfil the aims of the LTV.

Contents

FORM: F-WL-PP10-1 Versie 02
VALID FROM: 17/04/2009

1 Introduction

This report contains the final evaluation of the relocation tests near the Walsoorden sandbar, conducted in 2006 and 2007 within the context of the “Alternative relocation strategy for the Westerschelde – Continuation of the monitoring programme of the relocation test Walsoorden” (Alternatieve stortstrategie voor de Westerschelde – Voortzetting monitoringprogramma proefstorting Walsoorden). It contains the analysis of the results of the morphological and ecological monitoring programme, set up to assess the effects of the second relocation test in Walsoorden. This analysis includes a check of the criteria that were drawn up by the Flemish and Dutch experts prior to the relocation test of 2004 for the purpose of assessing the success or failure thereof.

2 Context

The Westerschelde forms the life line to the port of Antwerp. In order to guarantee port accessability, maintenance dredging works must be conducted in the channel. Due to the limited net sediment exchange between the estuary and the mouth area, the dredged material is disposed of within the estuary itself.

Until the second widening, carried out in 1997-1998, the material from maintenance dredging works was mainly disposed of in the secondary channels in the eastern section of the Westerschelde. Baring in mind the possibility that the continuation of this relocation strategy might endanger the multiple channel system in this area, the relocation strategy was altered after the widening of 1997-1998: since then, a large portion of the dredged material has been disposed of in the secondary channels in the central and western sections of the Westerschelde [1].

The increases in scale within shipping led to the port of Antwerp requesting further widening of the navigation channel. The fact that a widening project goes hand-in-hand with additional capital dredging works led to questions about the consequences thereof for the estuary and, more specifically, the multiple channel system. The Flemish and Dutch governments then drew up the Long Term Vision (LTV) for the Scheldt estuary in which the long-term objectives (2030) for the estuary are elaborated. These objectives must take the 3 following cornerstones into account: protection against flooding, ports accessibility and maintenance of the natural ecosystem of the estuary.

Parallel to the research for the LTV, an independent team of experts, at the request of the Antwerp Port Authority (Port of Antwerp Expert Team – PAET), formulated the idea that dredged material could also be disposed of outside the traditional relocation locations [2]. As part of the morphological management of the Scheldt estuary, PAET proposed that the relocation of dredged material ought to make a proactive contribution towards the achievement of the objectives for the estuary. The application of dredged material along the seaward tip of the Walsoorden sandbar [3] was put forward as a pilot project within the morphological management process.

On the basis of an historical analysis of soil maps, it was established that the tip of the Walsoorden sandbar had been significantly eroded over the last century (see Figure 1). This evolution was probably brought about by changes in the channel system between Terneuzen and Hansweert, whereby the flow to the sandbar had changed, as well as the morphological evolution of the Zuidergat. PAET proposed applying the dredged material at the tip of the sandbar and thus reconstructing the seaward sandbar tip.

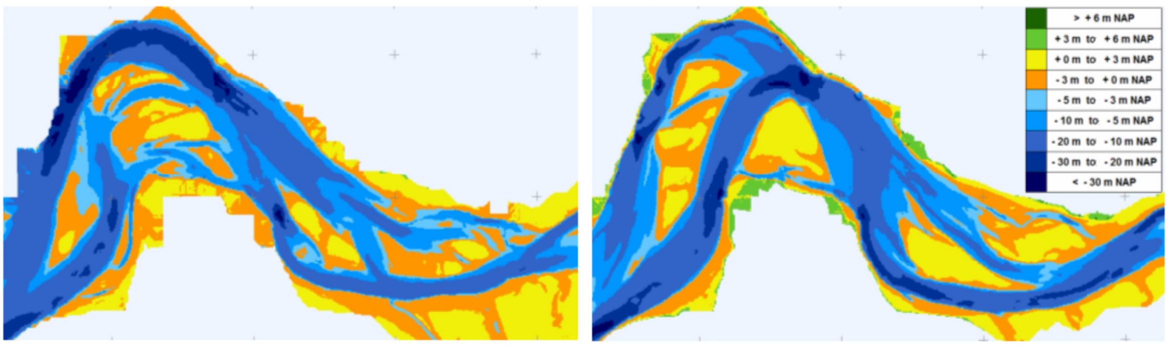


Figure 1 – Historical soil maps (left: 1931, right: 2003) from the Walsoorden sandbar

In order to check the feasibility of this idea, in 2002 Flanders Hydraulics Research was tasked with conducting a feasibility study.

3 Feasibility study and relocation test 2004

3.1 Feasibility study Walsoorden

In 2002 and 2003 Flanders Hydraulics Research in Borgerhout (WLB), a research centre for the Government of Flanders, investigated the feasibility of this proposed relocation strategy [5] on behalf of the Projectdirectie Ontwikkelingschets Schelde-estuarium (Project Directorate Development outline Scheldt estuary or ProSes).The study took place in collaboration with PAET which had prepared a proposal for a research programme and, together with the WLB, interpreted the results of the study.

The research programme encompassed the analysis of historical data (topo-bathymetry), in situ measurements in the Westerschelde and the use of physical scale models and numerical computer models. A field measurement campaign using dGPS-floats for the duration of a neap tide/spring tide cycle provided an excellent overview of the flow patterns near the sandbar. This data was also used for validating the models (physical and numerical). Sand transport over a full tidal cycle (13 hours) at various points at the location of the Walsoorden sandbar was also measured to gain an insight into the size and direction of this transport. The flow patterns around the sandbar were visualised (in addition to the float measurements) in the computer model and the existing scale model. Tests with movable material (polystyrene) were also conducted in the scale models (see figure 2) with the aim of determining the optimum relocation location for carrying out an in situ relocation test. None of the results from this study conflicted with the feasibility of the proposed strategy. However, an in situ relocation test would give final evidence that the proposed strategy is feasible.

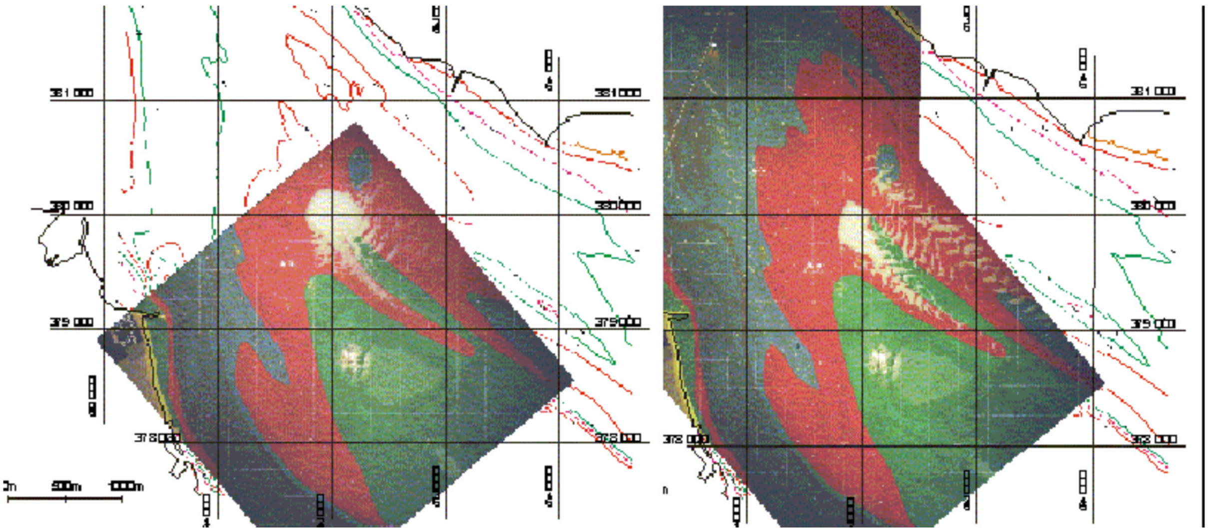


Figure 2 – Relocation of polystyrene in the scale model

A group of international experts were appointed by ProSes to form a judgement on the study conducted by WLB. In this “second opinion”, the experts endorsed the conclusions from the feasibility study by the WLB [6]. However, the final feasibility of the strategy would only be demonstrated after following-up an in situ relocation test and this, too, was confirmed by the expert group.

3.2 Relocation test 2004

Between 17 November 2004 and 20 December 2004, an in situ relocation test was carried out near the seaward tip of the Walsoorden sandbar: a quantity of 500,000 m³ of dredged material was disposed of at a location that was selected on the basis of the results of the feasibility study. The proposed location fell within the licensed relocation location of Schaar van Waarde but was a place at which no previous relocation had been carried out (see Figure 3).

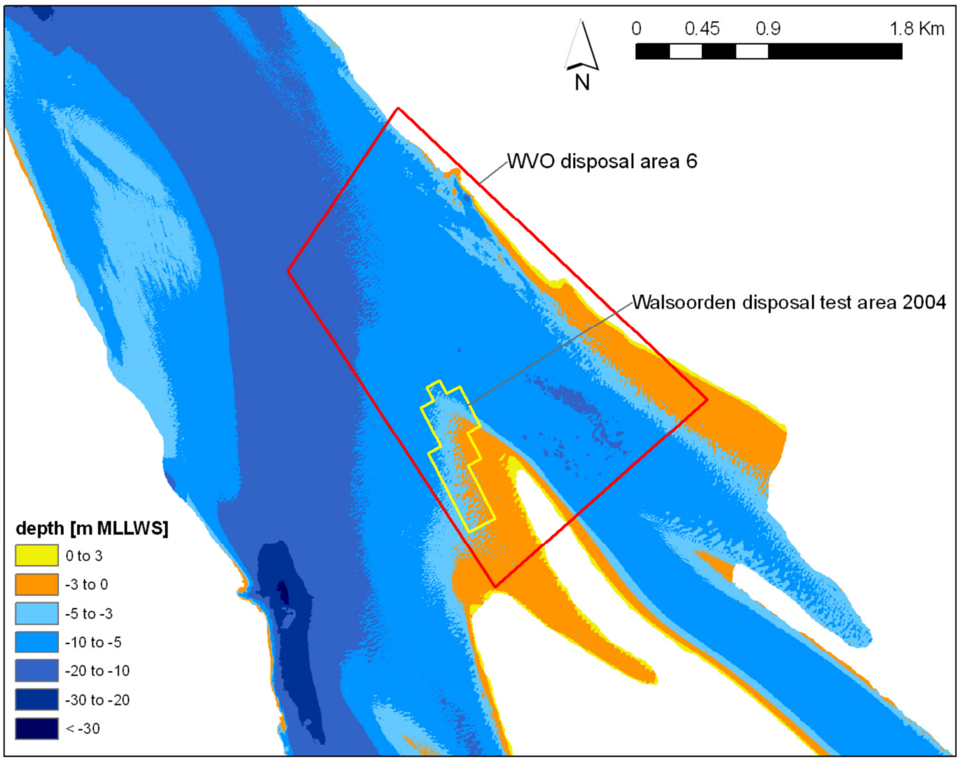


Figure 3 – Position of relocation test location 2004

In order to be able to dispose of this material accurately, use of the traditional method of relocation (so-called dumping or “clapping”), which involves the hopper of the dredging vessel being opened so that the material can sink to the bottom, was not proposed but, instead, a pontoon with a diffuser was used. This involves a special diffuser head that allows extremely accurate relocation in shallow waters. This would also allow the natural environment to be left as undisturbed as possible. Given that this relocation technique was not included in the ongoing WVO license (license from the Minister of Transport and Public Works), permission to employ it had to be requested.

On behalf of the Technische Schelde Commissie (Technical Scheldt Committee or TSC) a group of Flemish and Dutch experts drew up morphological and ecological criteria prior to the relocation test in order to assess the success or failure of the test itself. The emphasis lay on proving the stability of the disposed dredged material and the retention of the ecological balance on the Walsoorden sandbar.

An extensive monitoring programme followed up and checked the effects of the relocation test in relation to the criteria drawn up [7]. It transpired that the relocation test could be regarded as both a morphological and ecological success; the disposed material was very stable – 12 months after the completion of the relocation test, over 80% of the disposed material was still present within the control polygon. The applied material moved very slowly in the direction of the sandbar (flood-dominated transport) and this was in-line with the expectations of the feasibility study. This shift towards the sandbar is desirable in terms of the objective of reconstructing the seaward tip of the Walsoorden sandbar. The ecological results demonstrated no negative trends: there were no significant effects on the inter-tidal area as a result of the test. The height of the sandbar showed no deviation compared to long-term trends; the granulometry of the sandbar and the macrobenthos on the sandbar showed no deviation either as a result of the relocation test. A sub-tidal effect was established as a result of the relocation test: the sediment composition in the impact zone was slightly altered (decrease in mud- and semi-coarse sand-percentage, increase of sand and fine sand fraction). This was a result of a difference in granular size between the disposed material and the sediment that was initially present at the relocation site. This change in sediment composition, however, did not lead to a significant change in the sub-tidal macrobenthos.

4 Relocation test 2006

4.1 Introduction

After the morphological and ecological success of the relocation test which was conduced in 2004, a new relocation test was proposed (another 500,000 m³) to be carried out at the beginning of 2006. In contrast to the first test, this test would make use of the traditional relocation technique or "clapping" of the dredged material in order to ascertain whether this technique was just as suitable in terms of achieving the desired result (i.e. reconstructing the sandbar tip). This relocation test was conducted entirely within the remit of the relevant Transport and Public Works (WVO) license. The new relocation location was determined on the basis of in situ measurements, numerical modelling results and the experiences from the first test, taking into account the depth required for a fully loaded dredging vessel [8]. This location is indicated in Figure 4. Given that a different relocation technique was to be employed, where the draught of the dredging vessel is greater than that of the spraying pontoon, the relocation location was set further away from the sandbar compared to the 2004 relocation location.

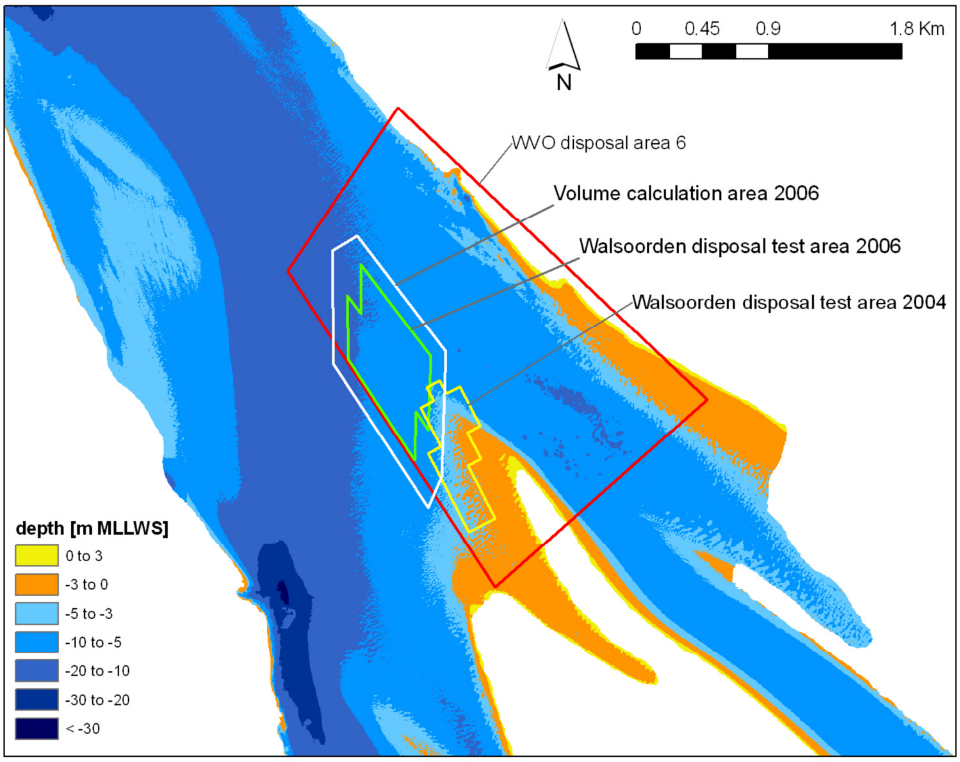


Figure 4 – Position of relocation test location 2006 (white) compared to relocation test location 2004 (yellow)

4.2 Objectives of the relocation test

The new relocation test was to investigate whether the traditional relocation technique could be used to achieve the objectives of the relocation strategy. Even though the applied material was expected to have high stability, it is possible that some of the material may be transported towards the sandbar by natural transport. In this way, the material functions as a "tracer" in order to assess whether, and at what speed, the disposed sediment shifts in the direction of the sandbar. The natural transport of the material under the influence of the tidal flow towards the sandbar is actually desirable if we consider the reconstruction of the seaward tip of the Walsoorden sandbar.

Finally, the efficiency of the relocation technique was also to be evaluated. The diffuser technique offers a much more accurate method of applying the dredged material to the riverbed, compared to the clapping technique. The relocation location of the 2006 test has a larger depth (necessary for trailing suction hoppers dredger), and is characterized by higher dynamics, both hydrodynamic (currents) as morphodynamic (sediment transports)..

Despite the fact that this is the second phase of an in situ relocation test, the disposed quantities for the test are still limited. This is in fact still a test, but with a different relocation technique and location compared to the first one. The objective, therefore, remains limited to checking the following aspects:

- The stability of the disposed material;
- The transportation of the disposed material towards the sandbar;

The objectives associated with the complete reconstruction of the sandbar tip encompass significantly greater relocation quantities and are not really the main subject of this test. The ultimate objectives are:

- Improving the distribution of the flood currents between the ebb and flood channel;
- Increasing the flow velocities in the channels adjacent to the Walsoorden sandbar, particularly above the sill of Hansweert. This would increase the self-eroding capacity of the currents and reduce dredging efforts;
- Reducing flow velocities on the sandbar, allowing finer sediments to settle in the shallow water and inter-tidal areas;

4.3 Evaluation criteria

The Technische Schelde Commissie (Technical Schelde Committee or TSC) insisted that criteria were drawn up prior to the relocation test in 2004 for the purposes of assessing the success or failure of the test. These criteria were collectively compiled by the group of Flemish and Dutch experts tasked with following up the relocation test.

Given that no specific criteria were drawn up before the 2006 relocation test, criteria analogous to the relocation test in 2004 were adopted as follows:

Table 1 – Assessment criteria for the relocation test

Description of criterion	Quantitative value of the criterion
Morphological criteria	
2 weeks after completion of the relocation test, only a certain percentage of the disposed quantities of sand are to have left the relocation area. **The relocation area will be established in draft via a coordinates file. The exact coordinates which will be taken into account for determining the disappearance of the sand will also be set 2 weeks after completion of the relocation test.** **The sand that ends up in the secondary flood channel to the north of the sandbar and just to the south of the Schaar van Waarde and which does not emerge above +2m NAP will not be included in the quantity of sand that has disappeared given that transport to the secondary flood channel is a desirable outcome.**	Maximum 20% of the total disposed quantity may have left the relocation site 2 weeks after completion of the relocation test. Between 20 and 40% of the material may disappear from the relocation site, if extreme conditions have led to this. Over 40% loss of material will be regarded as a failure of the test.
Sedimentation of the Schaar van Valkenisse as a result of eroded sediment from the relocation site may not occur, in particular if this corresponds to the formation of a bar in this adjacent channel. **A number of transverse transects are taken over the full width of the Schaar van Valkenisse; the transverse sections of these will be monitored. The multibeam**	Maximum 15% of the transverse profile of the Schaar van Valkenisse (at the location of the bar that now lies at the head of the Schaar) may have been occupied by sand 2 weeks after the completion of the relocation test.

surveys conducted immediately prior to the relocation test and 2 weeks after the end of the relocation test will be used for this.	
Ecological criteria	
Sedimentation of the Walsoorden sandbar is a detrimental ecological effect and will be followed up via sedimentation-erosion plots. No significant deviation from the long-term trend is to have occurred.	On 25% of the sandbar more than 4 cm, on 50% of the sandbar more than 2 cm or on 100% of the sandbar more than 1 cm will be regarded as a problem.
The inter-tidal areas at the height of the Walsoorden sandbar are relatively free of mud. Nevertheless, limited quantities of mud are important for ecology. The ecology is also sensitive to changes in the mud level. An excessive or insufficient mud concentration forms a problem.	On 50% of the sandbar more than 40% change in the mud level or on 100% of the sandbar more than 20% change in the mud level will be regarded as a problem.
The ecology may not be detrimentally influenced as a result of the relocation test. The macrobenthos, which is generally regarded as an important variable for monitoring changes in a marine environment, will therefore be monitored.	The density, biomass and diversity of the inter-tidal macrobenthos may not deviate from long-term trends.

4.4 Conducting the relocation test

The relocations were carried out within the context of continuous maintenance dredging work on the natural sills in the Westerschelde. In contrast to the relocation test in 2004, during which the material to be disposed of was supplied to the relocation site from the entire Westerschelde to allow the relocation test to be as effective as possible in the given time, the new relocation test took place within the context of day-to-day activities. As a result, the period required to dispose of a similar quantity was considerably longer (2 months versus 1 month). In addition and in contrast to the test in 2004, when a decision was made to use a diffuser for disposing in shallow water, this time the traditional relocation method, so-called “clapping” was selected. For this, the hopper on the dredging vessel is opened above the relocation location to allow the material to sink. The majority of the material then comes to rest on the riverbed although a limited quantity is transported by the flow and ends up elsewhere. This relocation technique is therefore less accurate than the method using a diffuser. The relocation site that was used in 2006 was deeper than the one selected in 2004 and this permitted the use of this relocation technique. Six different trailing suction hopper dredgers were used during the period of relocation in the set area.

Above left: trailing suction hopper dredger Jade River

Below left: detail of the suction head

Right: detail of the hopper

Figure 5 – A few photographs of the trailing suction hopper dredger Jade River

Even though the original intention was to conduct one new relocation test, the Maritime Access Division conducted additional relocations within the context of regular maintenance dredging work. As a result, the analysis will discuss a first phase (phase A) and a second phase (phase B).

During the first phase of the relocation test (phase A), from 14/01/2006 to 11/03/2006, an in situ volume of about 500,000 m³ was disposed of. The majority of this was discharged by the trailing suction hopper dredgers “Vlaanderen I” and “Jade River”, with a hopper capacity of 2,000 and 2,500 m³ respectively.

In autumn 2006, additional quantities were disposed of at this location. From 02/09/2006 to 17/03/2007 (relocation phase B), another in situ volume of 900,000 m³ was discharged in the set area, primarily by the trailing suction hopper dredgers “Manzanillo II” and “Jade River”, with hopper capacities of 4,000 and 2,500 m³ respectively.

The progress of the relocation is indicated in Figure 6. The blue dots indicate the disposed hopper volume per week. The blue and red lines indicate the cumulative volume: the blue line relates to the hopper volume; the red is converted into in situ volume. The difference between hopper and in situ volume is due to the lower density of the dredged material in the hopper compared to in situ. Calculations [9] demonstrated that the in situ volume, on average, was 10% less than the hopper volume.

This graph shows the distinct relocation phases (indicated by the yellow zones) and it is also notable that each of the relocation phases did not involve continuous relocations but included regular periods without any relocation at all. There is a notable, long period (9 weeks) during the second relocation phase where no relocations took place at all. This is in contrast to the relocation test in 2004, which involved four weeks of uninterrupted, seven days a week, relocation. The weekly relocation volumes also vary significantly. Since the last relocation on 17/03/2007, no more relocations have taken place at the location.

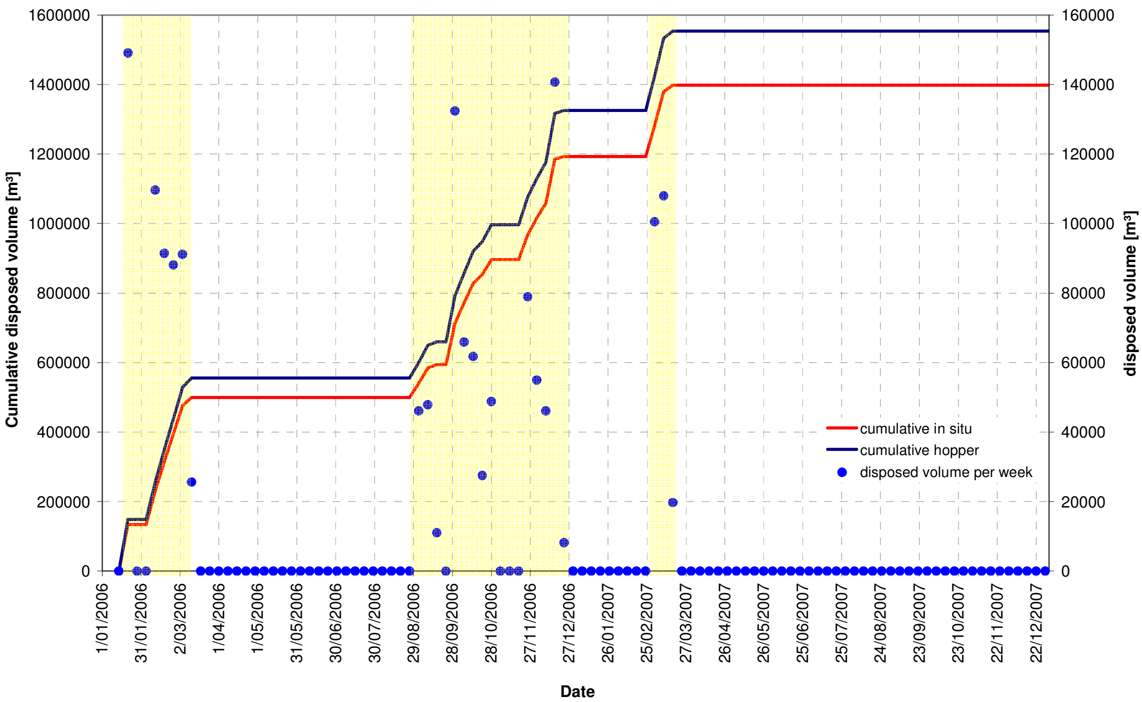


Figure 6 – Progress of relocation test; disposed volume per week can be read from the right axis.

5 Monitoring relocation test 2006

5.1 Introduction

A comprehensive monitoring programme was vital in order to be able to study the effects of the relocation test. This was conducted by external contractors. The monitoring programme can be largely split into two parts: a morphological section and an ecological section. This chapter will examine and discuss each section's approach and the results obtained.

5.2 Morphological monitoring

The multibeam echo-sounder technique was employed in order to monitor the topobathymetric changes in the area concerned. TV EUROSENSE BELFOTOP NV and EUROSENSE Planning & Engineering measured the study area from December 2005 with high-frequency, using a dual-head multibeam. A distinction can be made between the vast zone A and the more limited zone B (see Figure 7). These measurements are a continuation of the monitoring programme that was started in the context of the first relocation test.

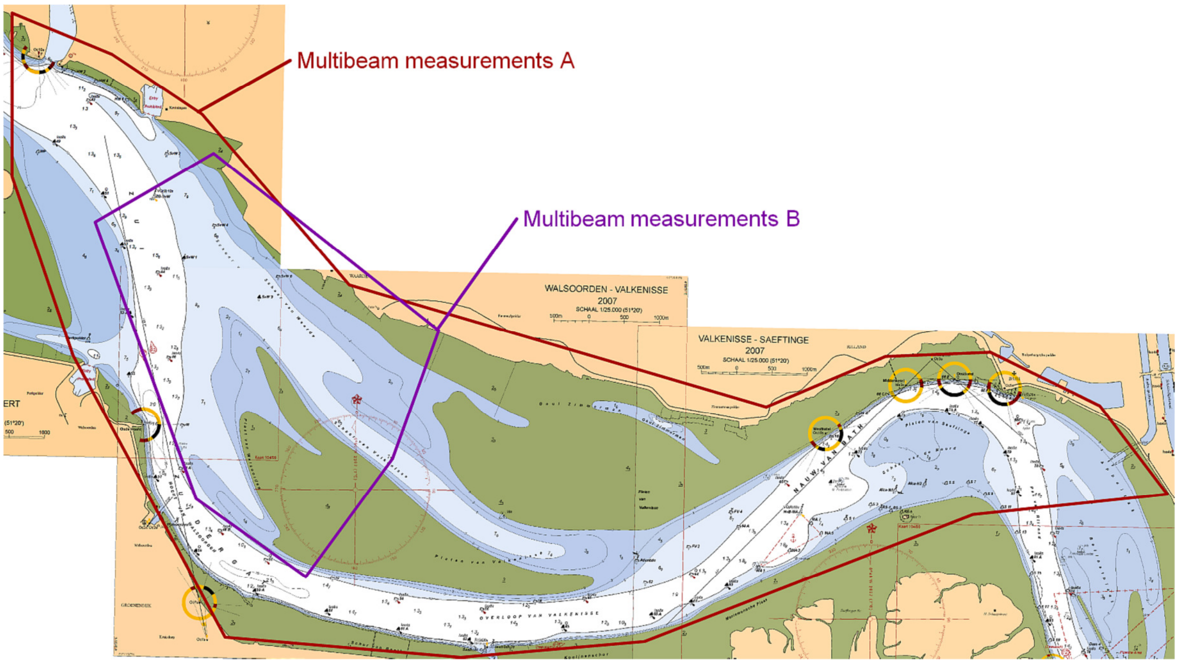


Figure 7 – Indication of multibeam recording zones A and B

- ZONE A: monthly soundings in 2006, bi-monthly from beginning of 2007 until September 2007. This zone, encompassing the area between Hansweert and Bath, was measured to 3.5 m below high water.
- ZONE B: weekly soundings from January 2006 to March 2006, soundings in April and May 2006, in November 2007 and in January 2008. This zone, encompassing the area surrounding the seaward tip of the Walsoorden sandbar, was measured to 1.5 m below high water.

A detailed list of the multibeam measurements conducted, with corresponding date of recording, is provided in appendix A.

5.2.1 Morphological evolution of relocation zone

a) Relocation phase A (14/01/2006 to 11/03/2006)

The result of the relocations carried out in the first phase are visualised in Figure 8. These are the results of multibeam echo-sounder measurements carried out during phase A of the relocation test, with an interim period of approximately one month.

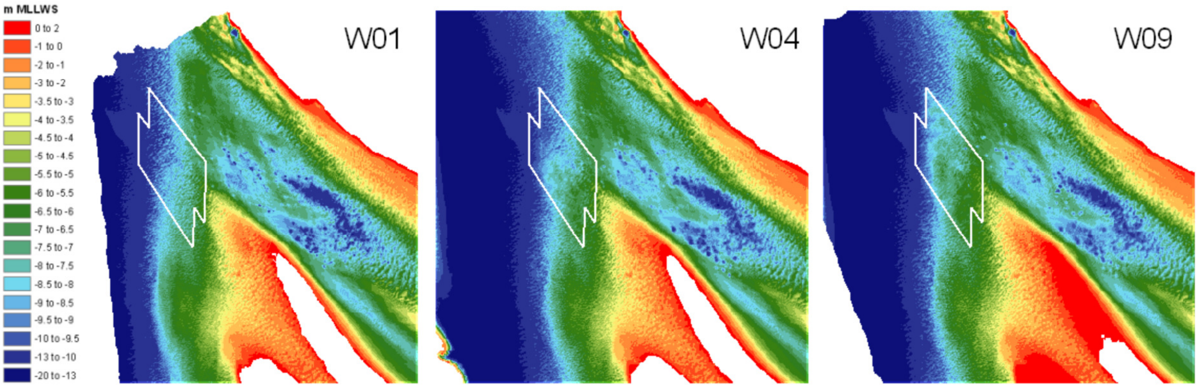


Figure 8 – Multibeam surveys during phase A of the relocation test; W number refers to period of recording (see appendix A)

In addition, Figure 9 shows the difference survey for the first month, the second month and, finally, the full period of relocation. This figure also shows that, in the first month, more relocations took place on the south-western side of the relocation site while, in the second month, the central point of relocation had shifted to the north-east.

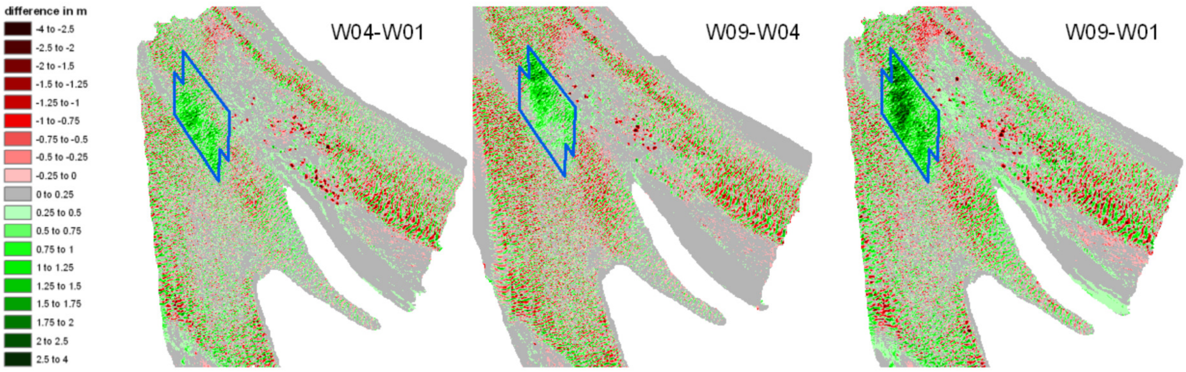


Figure 9 – Difference surveys during phase A of the relocation test

On the basis of the frequent multibeam measurements, the morphological evolution of the 500,000 m³ dredged material that was disposed of during the first phase could be followed in detail. Figure 10 shows the evolution of the disposed material with an interim period of about 2 months. No clear trend is visible here. This seems to point to the quite high stability of the disposed dredged material.

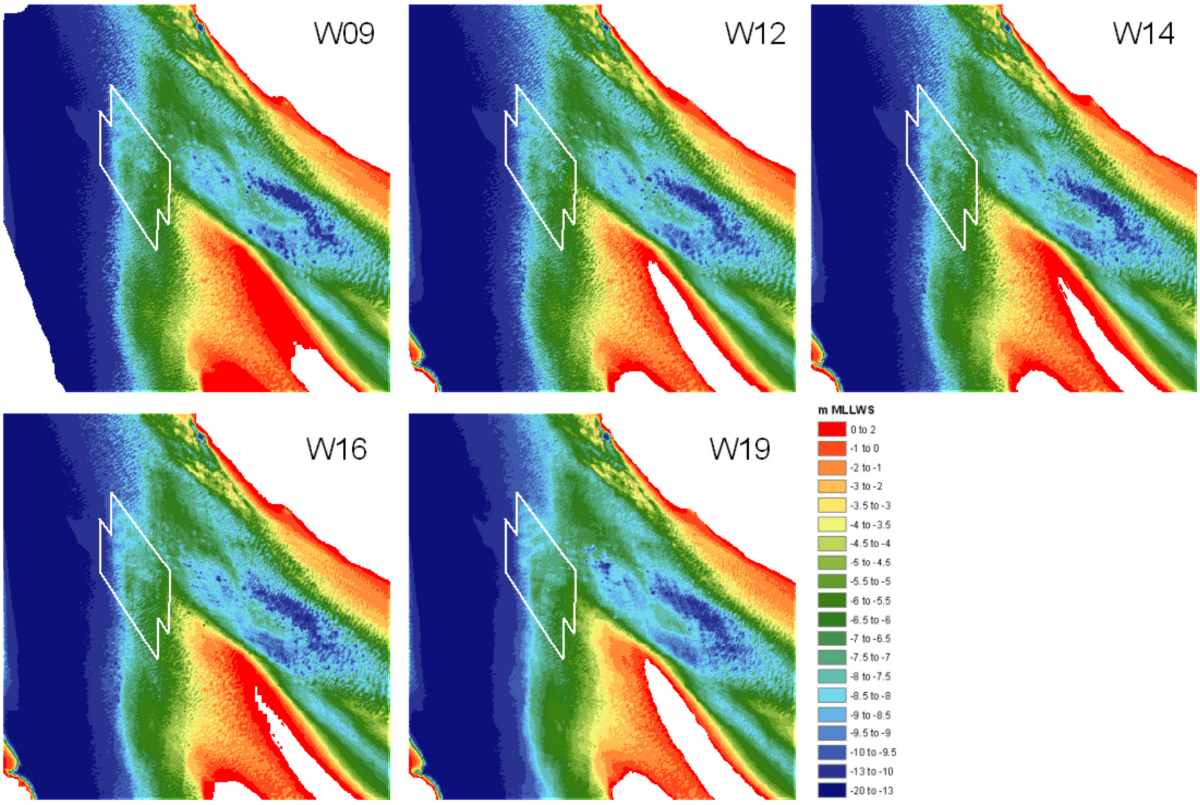


Figure 10 – Multibeam surveys after phase A of the relocation test; W number refers to period of recording (see appendix A)

The difference surveys 1, 2, 3 and 5 months after phase A of the relocation test (Figure 11), however, indicates a trend. The disposed dredged material has shifted towards the sandbar (alternating red and green north-east/south-west oriented strips). The transport of the material is visible from the second month and becomes clearer over time.

On the north-eastern edge of the relocation area, the effect of sand extraction can be seen (red dots on Figure 11). A sedimentation zone is also visible on the north-eastern flank of the northern sand spit. Analysis of dune propagation from 2000 to 2005 demonstrated that the transport of bedforms along the edge of the northern sand spit is ebb-dominated [9]. At the location of the relocation test, the flow is flood-dominated [10]. This means that, at the location of the northern tip of Walsoorden, where the ebb and flood-dominant zones come together, a zone is created without residual transport and this logically leads to the creation of a sedimentation zone. The material that makes up the sediment here can be partially transported from the relocation site but also from the more upstream ebb-dominated zone. Over the past few years, the northern side of the Walsoorden sandbar has undergone significant morphological change, as a result of morphological developments where the Schaar van Valkenisse and the Zuidergat connect. These morphological developments extend to the Schaar van Waarde and Valkenisse where there is the possibility of a turn in the northern sand spit and a change of ebb flow direction. This leads to an extremely complex and dynamic situation in this zone which hampers the assessment of developments.

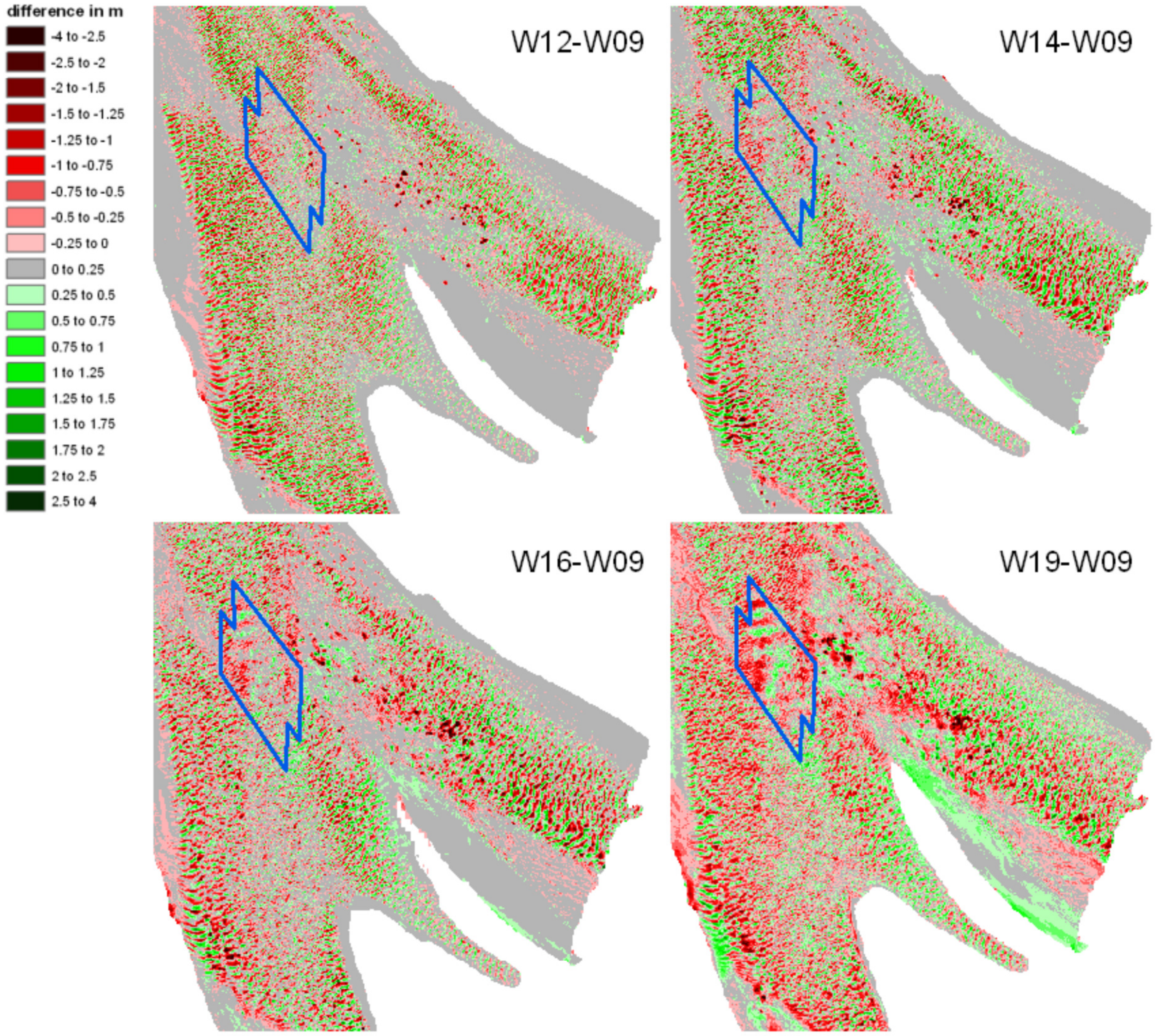


Figure 11 – Difference surveys after phase A of the relocation test

b) Relocation phase B (02/09/2006 to 17/03/2007)

The result of the relocations carried out in phase B are visualised in Figure 12. These are the results of multibeam echo-sounder measurements carried out during phase B of the relocation test, with an interim period of approximately one month. During this phase, around 900,000 m³ of dredged material was disposed of. Figure 13 shows the difference surveys from the first 4 months after the beginning of relocation phase B (W22-W19) and the 2 subsequent months (W25-W22). The last difference survey indicates the evolution over the entire relocation period. It can be seen that the relocations took place first on the north-western and then, primarily, on the south-eastern side of the relocation site. The dune pattern that was created by the first relocation phase was effectively flattened out. The difference surveys from the last 2 months show that there is already erosion of the disposed material on the western side of the relocation site.

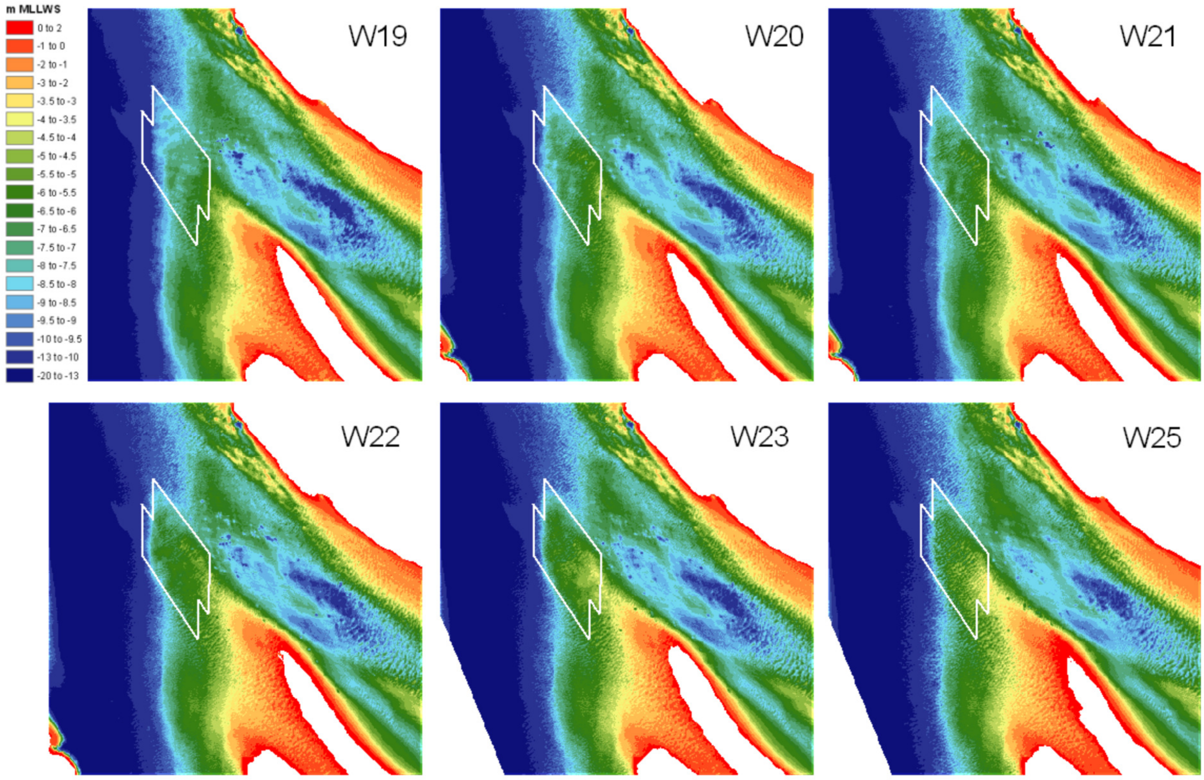


Figure 12 – Multibeam surveys during phase B of the relocation test; W number refers to period of recording (see appendix A)

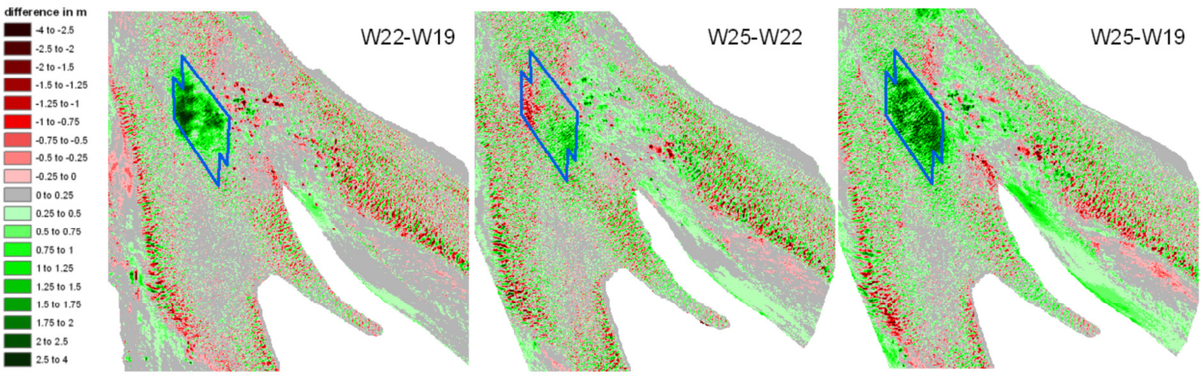


Figure 13 – Difference surveys during phase B of the relocation test

Figure 14 shows the multibeam echo-sounder recording after phase B of the relocation test: these figures show no clear changes, as was the case during the first relocation phase. In appendix B, on which the depth contours for -4 m MLLWS and -2 m MLLWS are indicated, a distinction can be established between the developments in the area on the seaward side of the northern sand spit and in the area to the south of this. An increase in the incline can be noted on the seaward side of the northern sand spit: the -4 m MLLWS line shifts towards the sandbar, while the -2 m MLLWS line shifts away from the sandbar with an enlargement of the area above -2 m MLLWS. In the area to the south of the sand spit, both depth contours are shifting away from the sandbar, with an enlargement of the area above -4 m MLLWS. This points to transportation of the disposed material towards the sandbar but this trend is not particularly clear-cut.

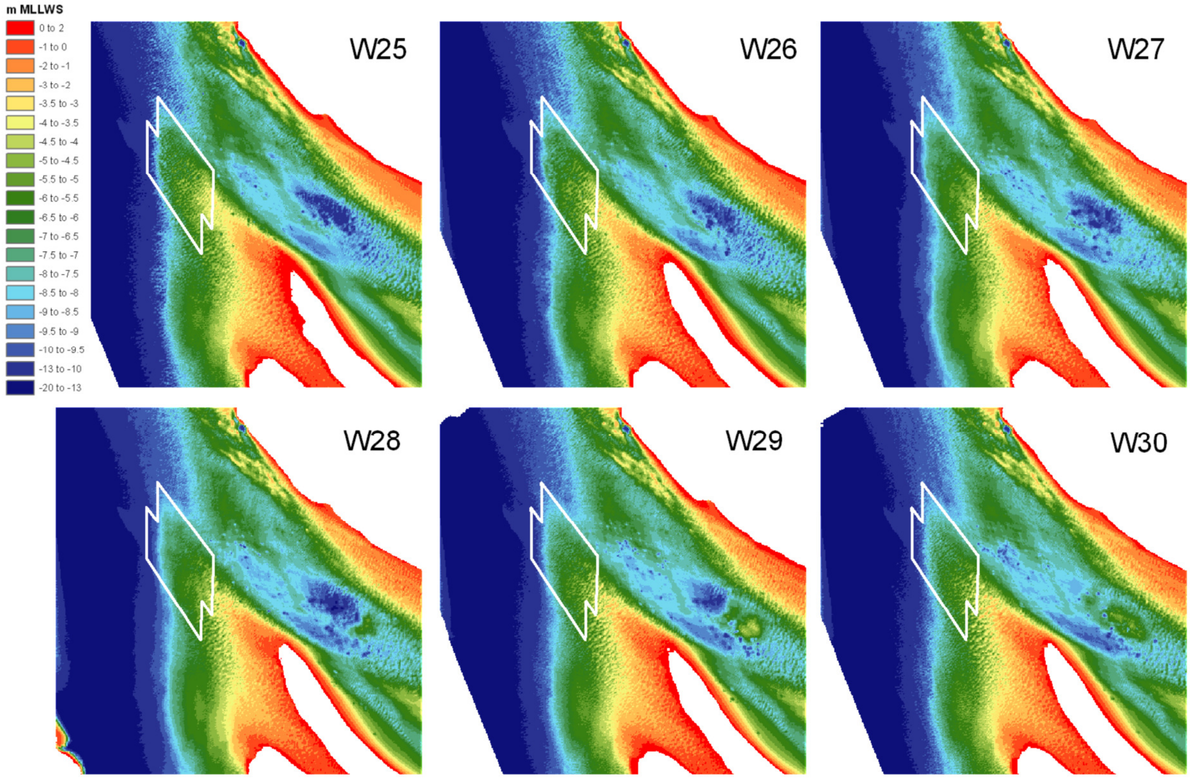


Figure 14 – Multibeam surveys after phase B of the relocation test; W number refers to period of recording (see appendix A)

Figure 15, the difference surveys 2, 6, 8 and 10 months after completion of the relocations in phase B, give a clearer picture: there is a sedimentation zone between the relocation site and the Walsoorden sandbar (at the location of the 2004 relocation site) which is gradually expanding in the direction of the sandbar. Furthermore, just like after phase A of the relocation test, the effect of sand extraction along the northern edge of the relocation area is visible, as is sedimentation on the edge of the Walsoorden sandbar’s northern sand spit.

The difference surveys after both phases of the relocation test show that there is also erosion along the seaward side of the relocation location, although the material seems to have settled mainly between the relocation area and the sandbar which can be regarded as a positive trend. In paragraph 5.2.5, a quantitative analysis on the basis of volume calculations examines this trend more closely.

These difference surveys also clearly show the relocation conducted in the Schaar van Waarde in 2007. At this time, concentrated relocations were carried out in a part of the Schaar van Waarde relocation area that had been proposed within the context of the relocation test 2006 in order to impact upon this test as little as possible.

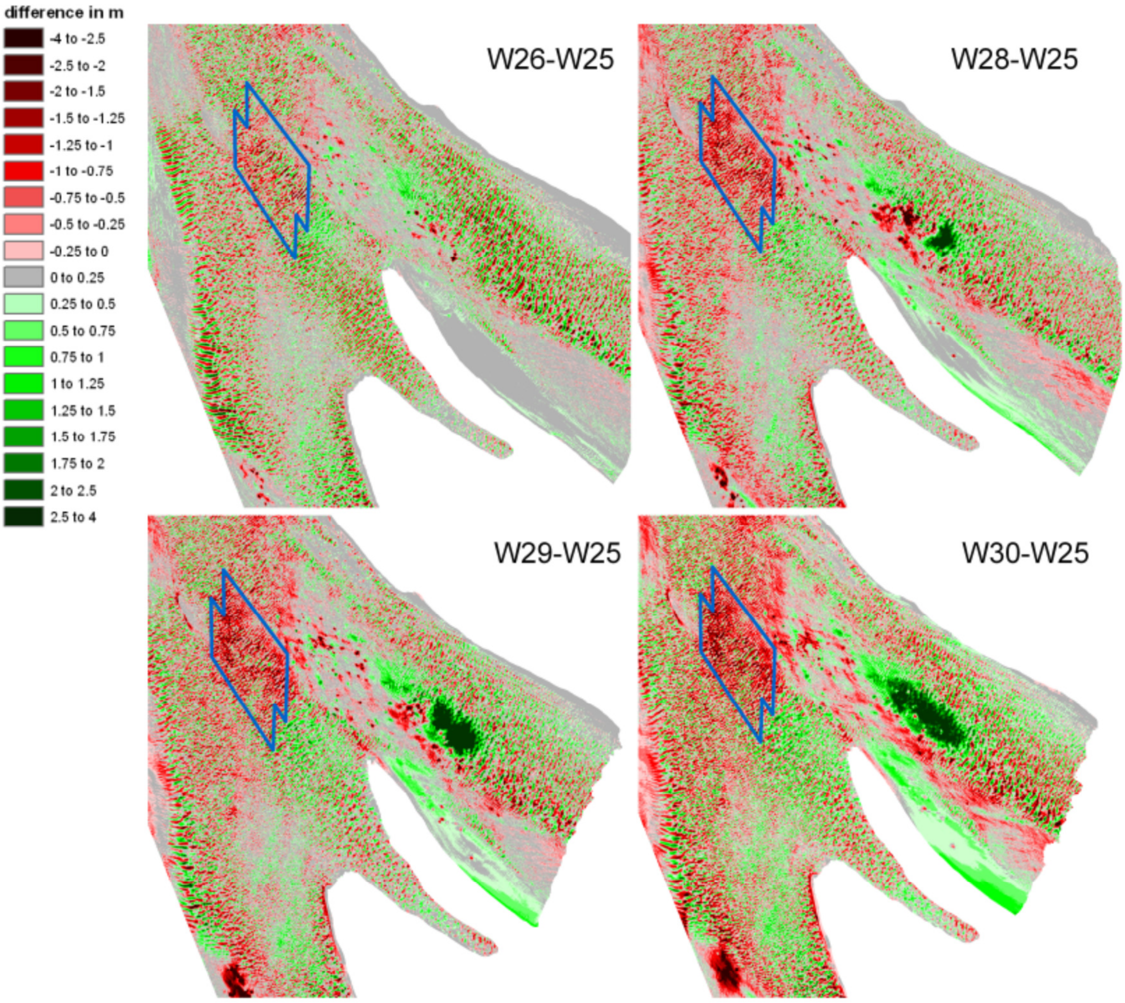


Figure 15 – Contrast soundings during phase B of the relocation test

5.2.2 Stability of disposed material

In order to check the stability of the disposed material, a control polygon – enveloping 100 meters around the area of the relocation test – was defined, in which the sand balance was then studied. This control polygon is indicated in Figure 4 (green contour).

The results of the volume calculations are given in Figure 16. Three lines are shown on this graph: the cumulative (in situ) relocation quantities (orange), the sand volume within the control polygon compared to the initial sand volume (green) and the percentage volume change within the control polygon after execution of the relocation test (blue). It must be noted here that the volume quantities are expressed in “in situ m³”. The periods of relocation are indicated with a yellow background.

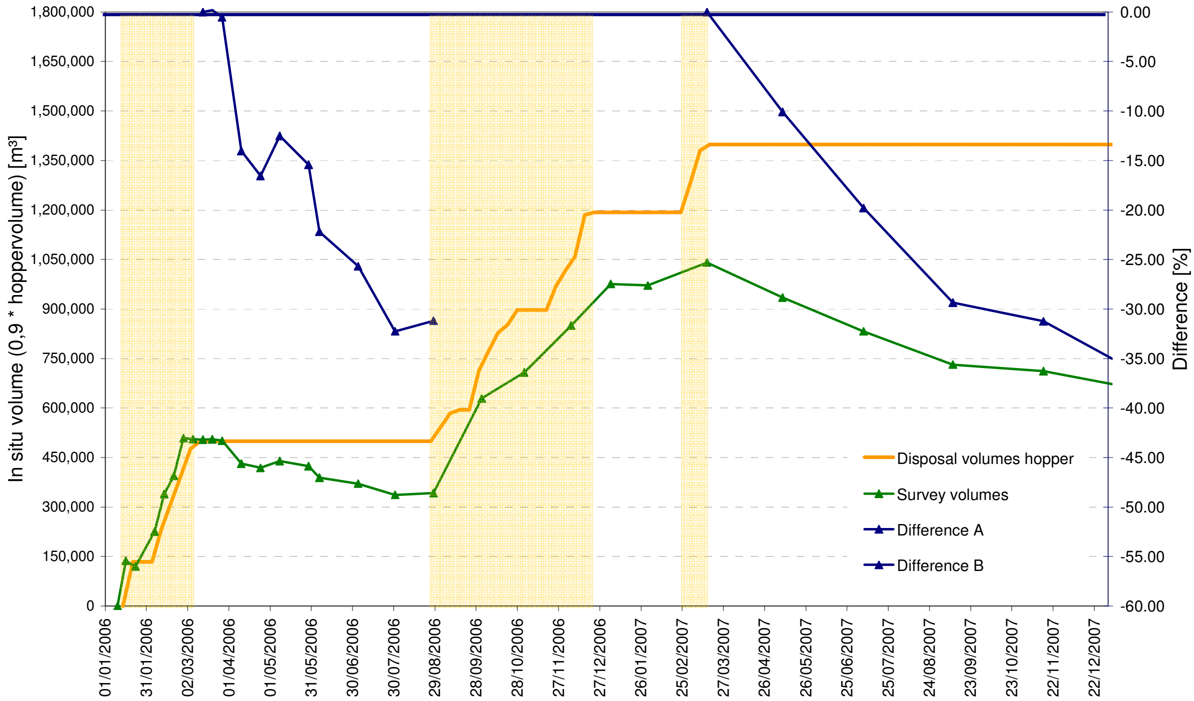


Figure 1 – Volume calculations on the basis of multibeam echo-sounder soundings

This graph demonstrates that the quantity of sand within the control polygon remained relatively constant for one month after relocation phase A. A reduction, however, is clear from the beginning of April 2006 – 1 month after the end of relocation phase A – and this was then followed by a more constant phase between the end of April and the end of May. Thereafter, the sand volume reduces again until the start of relocation phase B. Around six months after the relocation, about 30% of the disposed volume had disappeared from the control polygon.

During the relocation test in 2004, a reduction of the sand quantity was not observed right after relocation, a slight increase was, in fact, detected. This phenomenon is ascribed to changes in the local dynamics: under the influence of locally changed hydro-dynamics, transported material was able to settle at the location of the relocation zone. Given that the relocation during this trial took place in a deeper zone, which shows higher dynamics, both hydrodynamic as morphodynamic, such disruption by limited relocation is less likely. In addition, the occurrence of a second constant phase, not linked to the relocation of additional material, is more likely to point to a natural variation in sand transport, with changing erosive and less-erosive phases.

Relocation phase B was immediately followed by a reduction in sand volumes within the control polygon. Here, there was no notable change between phases during which reduction took place and the more stable phases. It must be noted, however, that the frequency of recording after phase B was lower than that of the earlier relocation tests. As a result, developments in the sand volumes in the short term will not be observed. The reduction continued to the end of 2007, but slowed over the course of time. Almost 10 months after the end of relocation phase B, around 35% of the disposed quantity had disappeared from the control polygon.

Making an effective quantitative comparison with the relocation test in 2004, however, is difficult in this case, given that consideration must be made, for the 2006 relocation test, of the two separate relocation phases and that relocation phase B included a relatively long period during which no relocation took place. At the beginning of relocation phase B, the erosion following relocation phase A was still going on and this means that the natural dynamic at the location of the relocation zone was still disrupted. During relocation phase B, the transport of the material disposed of in relocation phase A continued. Moreover, noting the longer duration of relocation phase B, with a few periods in which no relocation took place, some of the disposed material was already transported during the relocation phase. Relocation and transport phases cannot, therefore, be examined separately for this relocation test. Even though about 900,000 m³ was disposed, a volume increase of just 700,000 m³ can be established at the end of relocation phase B. This would suggest that some of the material had already been transported by the flow during the relocation phase.

A comparison of the total dumped quantity during the complete relocation test (phase A and phase B, around 1,400,000 m³) and the volume increase in the control polygon between the beginning of relocation phase A and the end of relocation phase B, shows that just 1,041,000 m³ of the disposed volume was present in the polygon at the end of the relocation test. During the relocation test (relocation phase A and relocation phase B) itself, about 25% of the disposed material was transported to outside the control polygon.

At the end of 2007, just 50% or around 700,000 m³ was present in the control polygon. Further analysis of the sounding data from 2008 demonstrates that by September 2008 (a year and a half after the end of the relocation test), 60% of the disposed material had disappeared.

In addition to transport outside the control polygon, the difference between the disposed material and the observed volume increase within the control polygon may also be explained by lower relocation efficiency. During the first relocation test in 2004, use was made of a diffuser with a spraying head and this led to an efficiency of around 85% [9]. On the basis of relocations in 2005 in the Schaar van Waarde, an average relocation efficiency of around 69% was calculated for the traditional clapping technique [9].

Relocation efficiency was also calculated for the relocation tests in 2006. Given the greater duration, 2 periods within the different relocation phases were selected for calculating relocation efficiency. In order to exclude the impact of material transport as effectively as possible, an attempt was made to choose a period for which multibeam measurements were available that closely connected to the relocation period and within which there were no significant periods without relocations. For relocation phase A, the period between W01 and W09 was chosen; this spannes the entire relocation phase. The relocation efficiency for this period amounted to 84%. For relocation phase B, the period between W19 and W21 was selected, within which there were only short periods without relocations. The relocation efficiency for this period amounted to 73%. It is possible that the lower value in relocation phase B was caused by periods without relocations during which erosion could occur. It must also be noted that no correction was made in relation to the calculation of relocation efficiency for the purposes of compensating for variations in the density of dredged material in the hopper and in situ. It is assumed that the in situ volume amounts to 90% of the hopper volume as a result of density differences. If this factor had been taken into account, a higher relocation efficiency level would have been achieved.

Part of the reduction in sand volumes that was recorded within the control polygon can also be put down to sand extraction on the edge of the relocation area that occurred within the control polygon. This, however, involves pretty limited volumes.

The control polygon was defined as enveloping the relocation area, with an equidistant space (100 m) to each side of the relocation area. Given, however, that transport of material towards the sandbar was expected, the disappearance of relocation material from the control polygon towards the sandbar cannot be regarded as a negative effect. The detailed analysis of the relocation (see par. 5.2.5) further examines the volume changes towards the sandbar and the impact of sand extraction.

5.2.3 Development of bedforms

The longitudinal transects (Figure 17) through the relocation zone and in the secondary flood channel (between the northern sand spit and the sandbar tip) allow the development of bedforms on the relocation site and downstream of the sandbar to be examined. A longitudinal control transect is also defined outside the impact zone of the relocation tests.

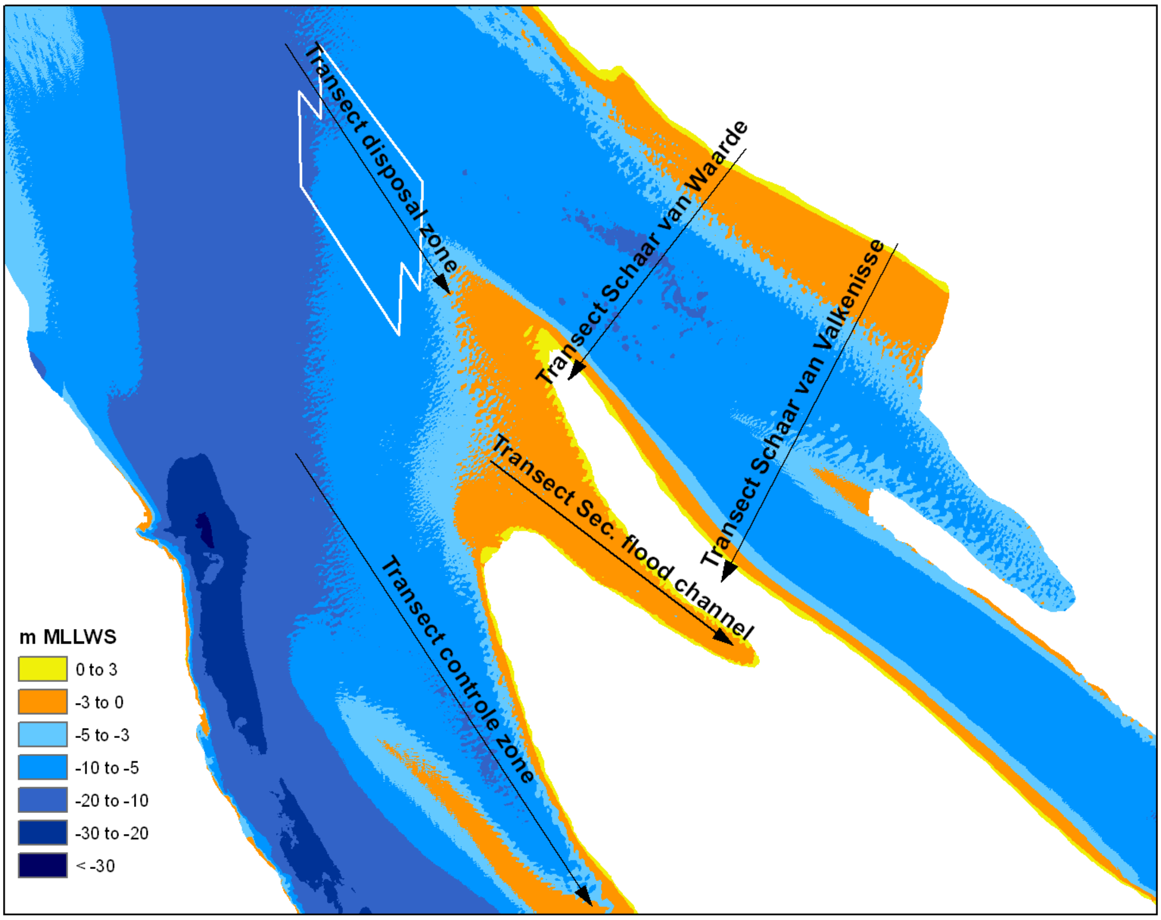


Figure 17 – Location of transects

a) Relocation phase A (14/01/2006 to 11/03/2006)

Figure 18 shows a profile of the longitudinal transect through the relocation area during relocation phase A (image with high distortion). The direction of the transect is similar to the direction of the flow which is determined by physical and numerical modelling. The position of the relocation area in the profile is indicated with a yellow square.

The red line (W01) shows the situation before the relocation test, at which time individual bedforms of an average of 1.5 m high and 30 m long were visible. At the end of the relocation phase (W09 – green line), the relocation is clearly visible in the seaward part of the relocation area. The bed is raised by about 1 to 1.5 m in this area. Bedforms that are about 0.5 m high and 15 m long have already developed on the relocation itself. In subsequent months, the disposed material migrates towards the sandbar at a speed of about 25 m per month. The individual bedforms reduce in height over the course of time and evolve, six months after the relocation, into an average height of approximately 20 to 30 cm and an average length of 10 m. Normally, the opposite effect would be expected, i.e. that the bedforms flatten off after relocation and then develop once again. It is suspected that this can be put down to a seasonal effect and this is confirmed by Figure 19, which shows the profile through the longitudinal control transect. The individual bedforms for W19, measured on 28/08/2006 (in the summer) are much smaller than the bedforms in the winter, e.g. W01 (12/01/2006).

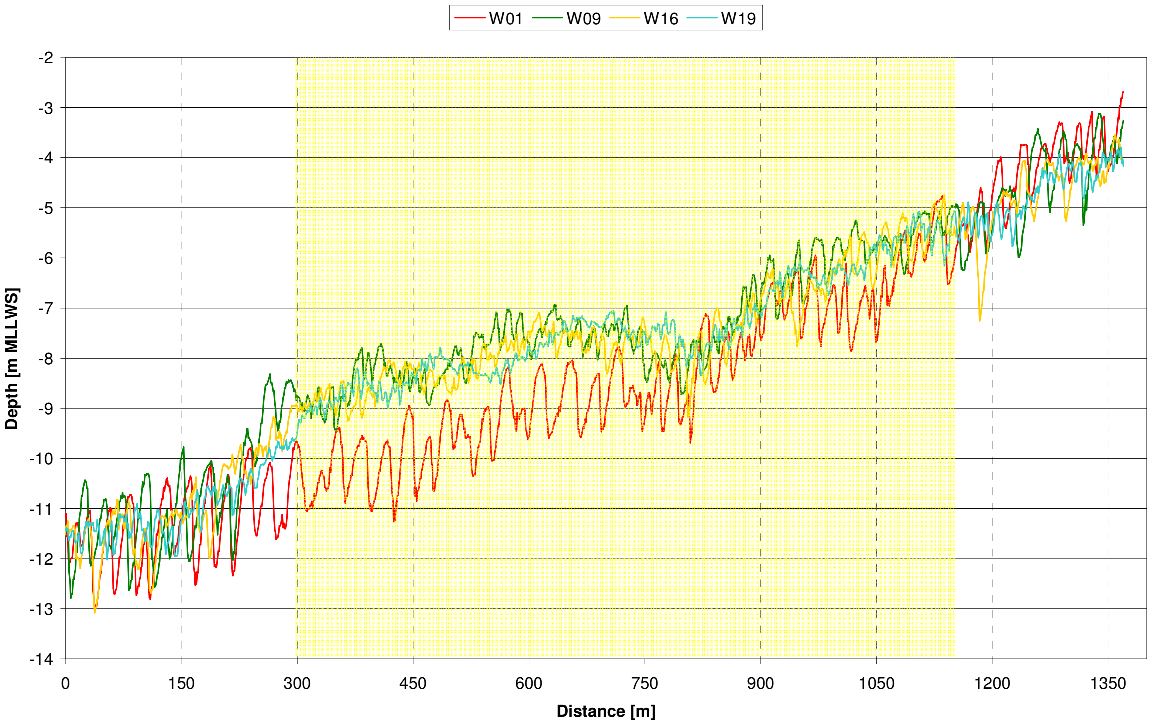


Figure 18 – Evolution profile longitudinal transect through the relocation zone during and after relocation phase A

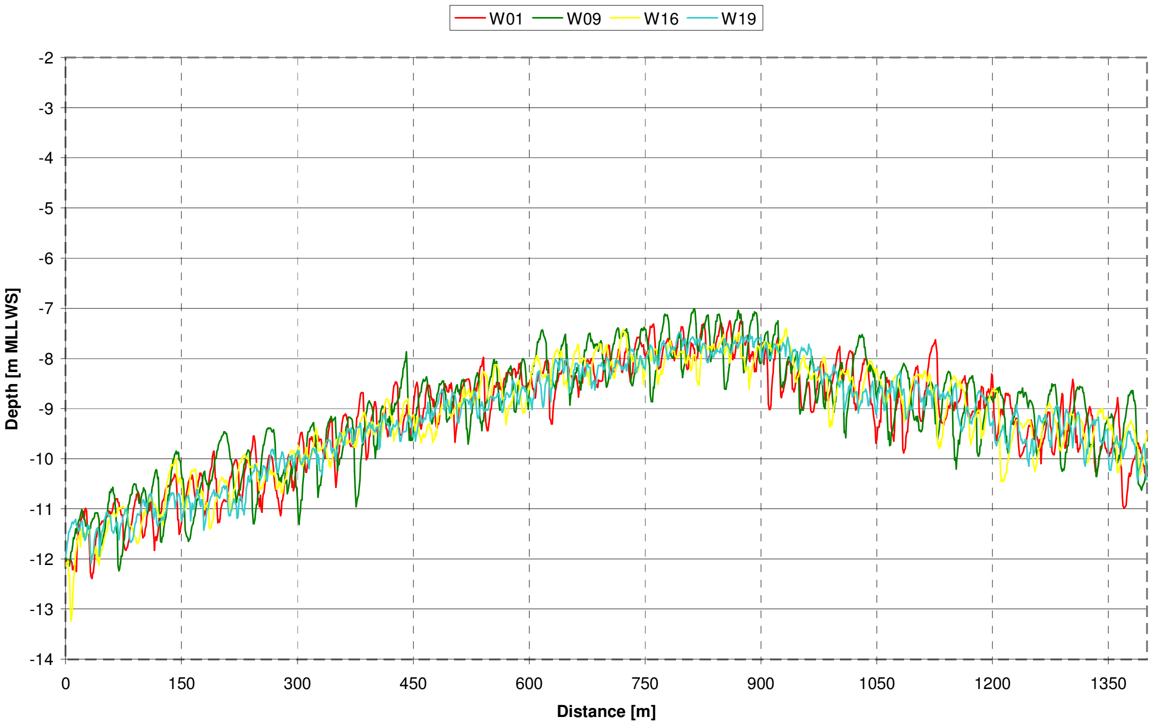
A quantitative image of this reduction in size can be obtained on the basis of a routine within the Matlab which was programmed in the context of the project concerning habitat mapping in shallow water [10].

This analysis was applied to the W01 and W19 situation for both the longitudinal transect through the relocation site and the control transect; the outliers (anything that deviated more than 75% from the average value) were removed. This showed that, in winter, the average bedform length along the longitudinal transect (W01) is 24 m and the average bedform height is 1.3 m. In the summer (W19), these measurements reduce to 12 m and 0.3 m respectively, as had already been estimated.

The same analysis for the control transect provided a winter (W01) average bedform length of 21 m and average bedform height of 1 m, compared to a length of 13 m and a height of 0.5 m in summer.

The morphological developments within the relocation zone were further investigated on the basis of the shaded view images of the relocation zone before (W01), during (W04), right after (W09) and 5 months after (W19) the relocation (see Appendix C). Before the relocation test, a uniform pattern of ripples is visible within the zone. After execution of the first half of the relocation (W04) there is a visible elevation in the south-western part of the relocation area and the bedforms in this zone have flattened out. Right after relocation phase A (W09), results from the relocations can also be seen in the north-eastern part of the relocation area. There are two issues worth noting: on the one hand, relocation in the north-eastern part took place in 3 separate ‘relocation piles’ and, on the other, there is the development of small ripples on the relocation itself (both in the north-eastern and the south-western parts of the relocation area). W19 shows that the relocation piles are still visible 5 months after but have shifted towards the sandbar and are, therefore, behaving like dunes that are shifting, via migration, towards the sandbar. The size of the bedforms has become smaller over the entire area as a result of seasonal differences; the bedforms on the relocations, however, remain smaller than those in the surrounding areas.

A better image of the relocation piles can be seen on the figures in appendix D, where profiles for W01, W09 and W19 are given together with their floating average (cf. aforementioned matlab routine), for a transect in the northern and southern half of the relocation test area (location of transects is given in red in figure D1). Given that the floating average is used for ‘detrending’, i.e. to separate the underlying topography and large-scale bedforms from the individual, smaller bedforms, the floating average provides a good overview of the underlying topography.



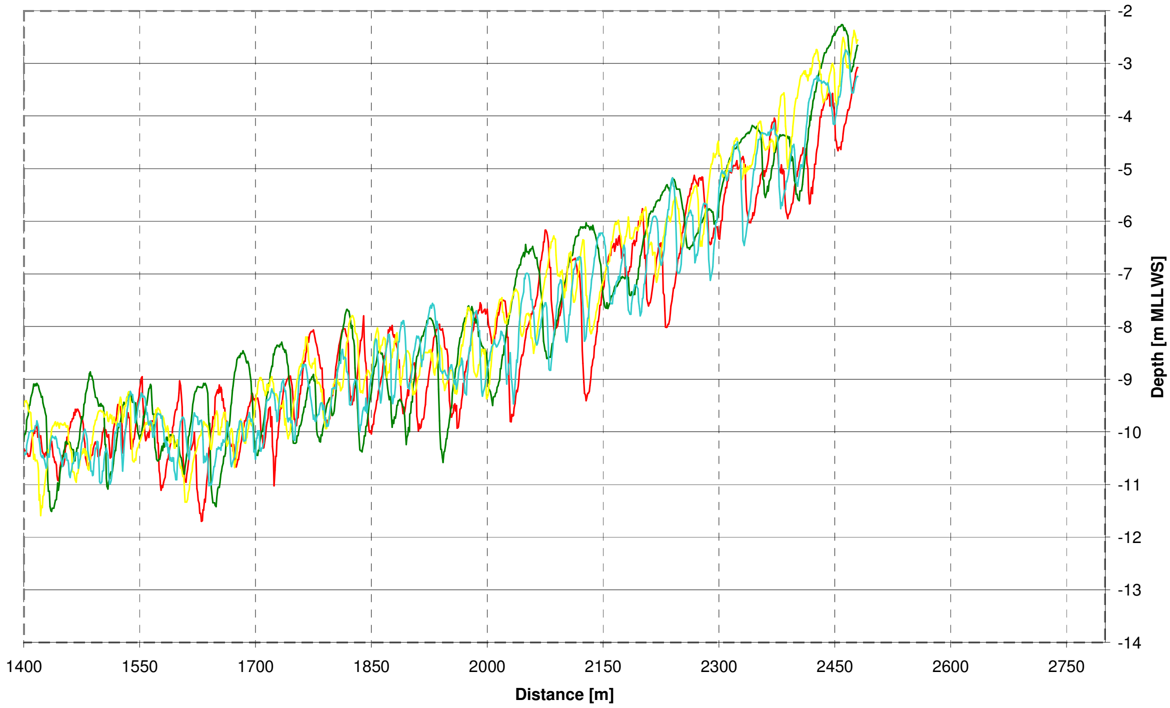


Figure 19 – Evolution profile of longitudinal transect through the control zone during and after relocation phase A, above: north-western part of the transect, below: south-eastern part of the transect

We note that there is a gradual increase during W01 (figure D1) both for the northern and the southern profile. After the relocation, there is a clear distinction between the profile in the north and the profile in the south for profiles during W09 (figure D2). In the north, the relocations are concentrated further away from the sandbar (between 200 and 800 m), whereas for the southern transect the relocations are located closer to the sandbar (between 300 and 1100 m). The relocations migrate slowly towards the sandbar: compared to the W09 situation, there is a migration of 100 metres towards the plate in W19. The reduction in size of the secondary bedforms compared to the winter condition is visible in both profiles.

Figure 20 shows the evolution of the longitudinal transect through the secondary flood channel, between the sandbar tip and the northern sand spit. Here, no increase in height is visible and this indicates that the dredged material that has been eroded from the relocation site has not (yet) shifted to the secondary flood channel.

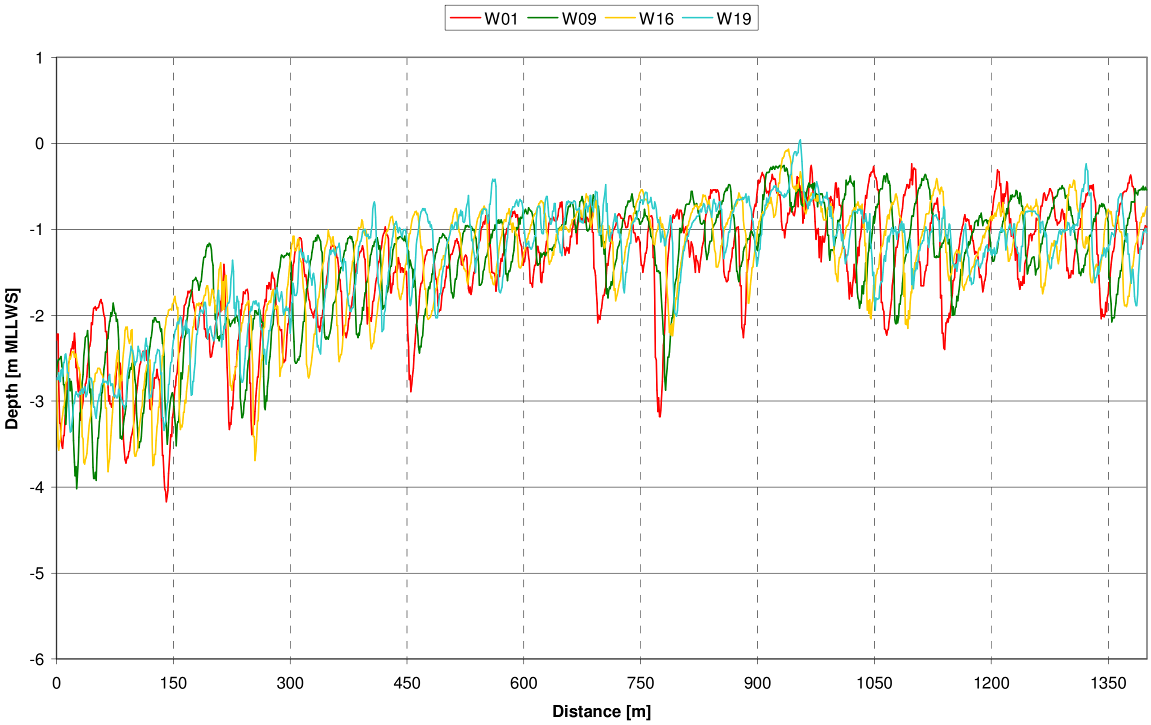


Figure 20 – Evolution profile longitudinal transect through the secondary flood channel during and after relocation phase A

b) Relocation phase B (02/09/2006 to 17/03/2007)

The same effect is visible for relocation phase B as was the case with relocation phase A (see Figure 21): the profiles of W19 (28/08/2006) and W27 (07/07/2007) show smaller bedforms than those of W25 (15/03/2007) and W30 (07/01/2008), both inside the relocation test area and in the control transect. The exception is the curve from January 2007, W22: here, the bedforms are quite flat in the relocation area even though this measurement took place in the winter. Only W19 and W27 have flattened out in the control transect (see Figure 22). W22 was, however, measured during the execution of the relocation test (the second relocation phase ran from W19 to W25). So, here flattening as a result of the relocation does play a role.

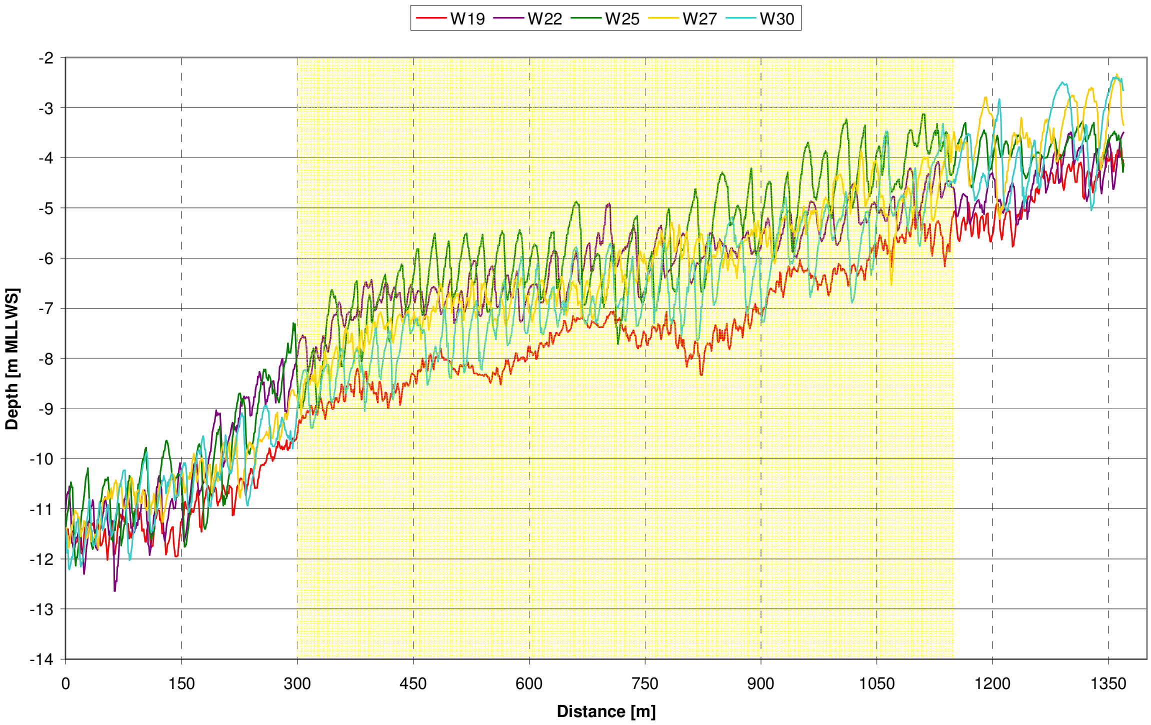
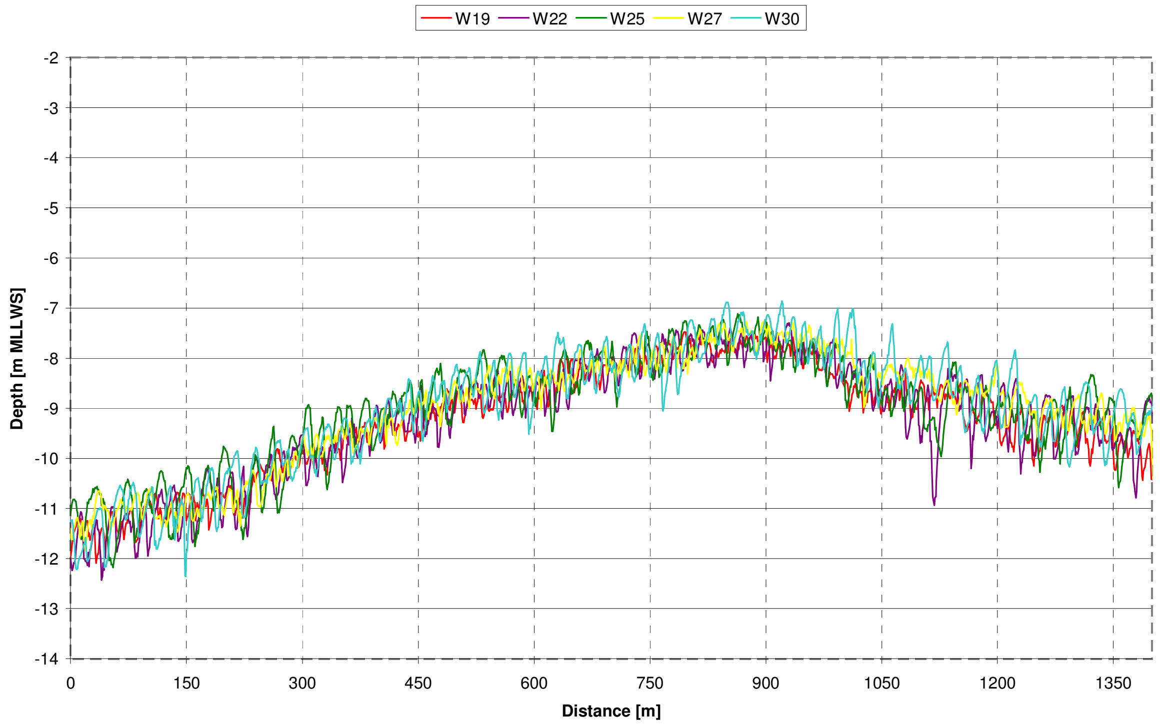


Figure 21 – Evolution profile longitudinal transect through the relocation zone during and after relocation phase B

Figure 23 shows the evolution of the longitudinal transect through the secondary flood channel during and after relocation phase B. As with relocation phase A, no trend is visible; even seasonal differences cannot be distinguished.

Both after relocation phase A and relocation phase B, the natural dynamism of the system recovers quickly after relocation, in contrast to observations made just after the 2004 relocation test. Here, it took a few months for the bedforms to revert to what they had been. This is probably a result of the difference in relocation technique. With clapping, the thickness of the settled disposed material is smaller than with the use of a diffuser. In addition, clapping requires greater depths, which means that the dynamics in the relocation zone is also greater. This latter factor, in particular, will positively influence the recovery of bedforms after relocation. The period of relocation also probably impacts upon the speed of recovery, given that there is a clear difference in the dynamism of the system between summer and winter.



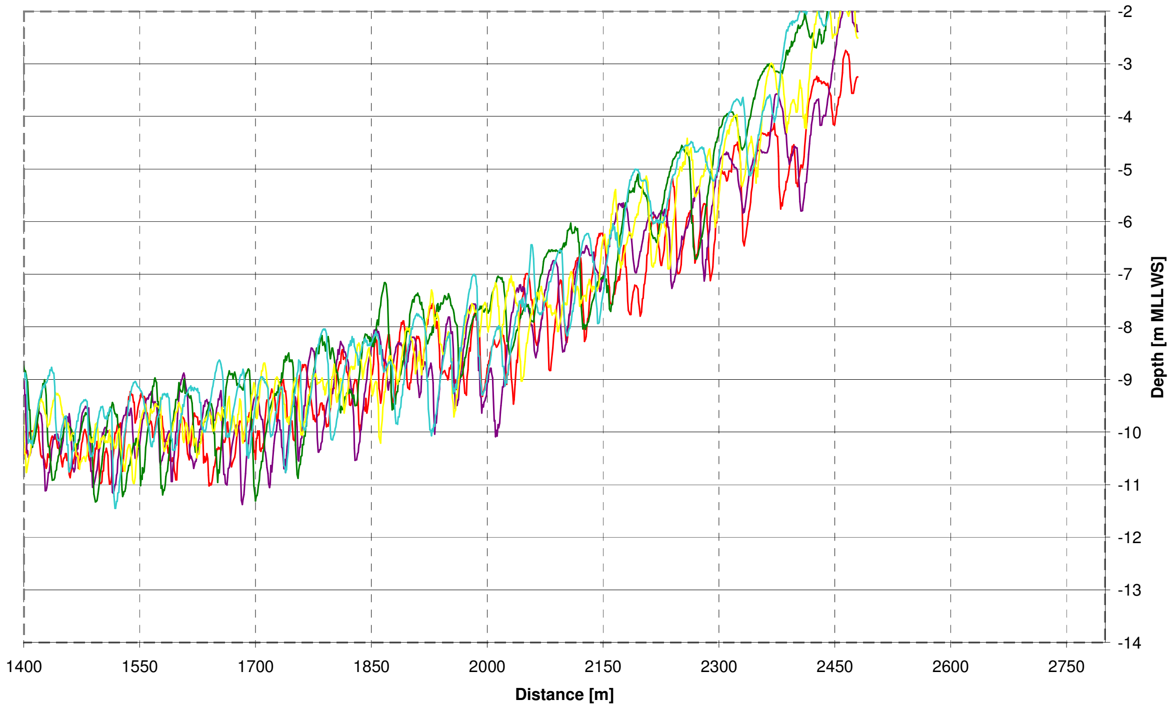
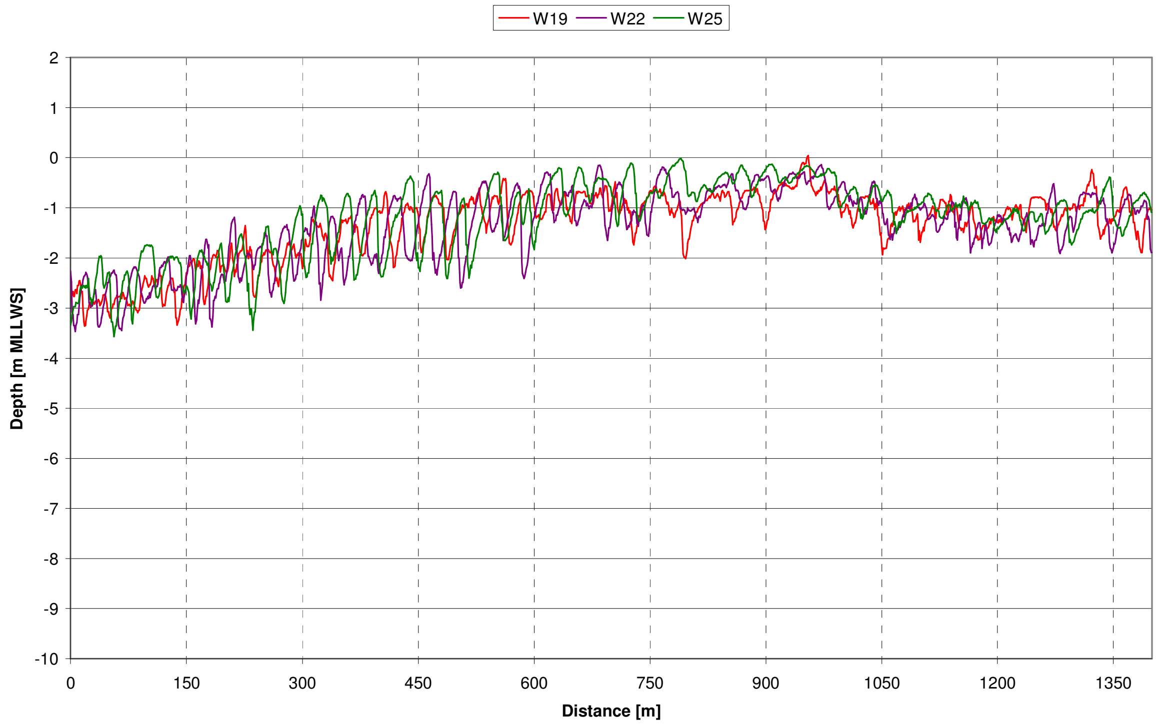


Figure 22 – Evolution profile of longitudinal transect through the control zone during and after relocation phase A



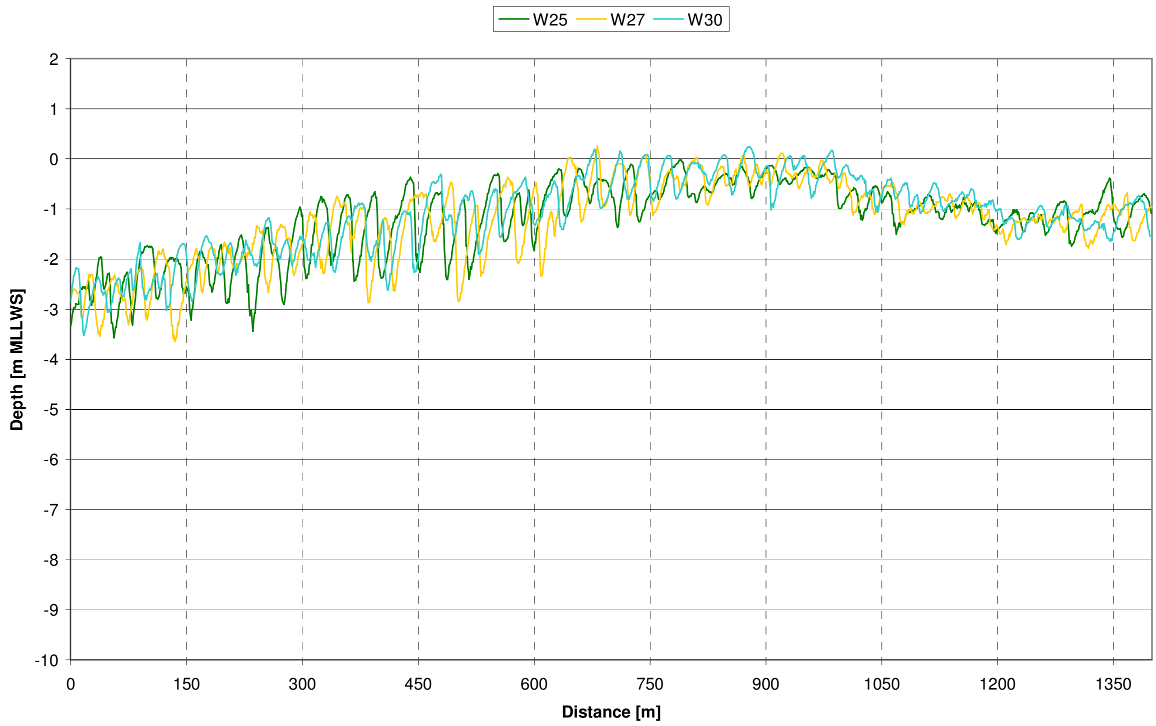


Figure 23 - Evolution profile longitudinal transect through the secondary flood channel during and immediately after relocation phase B (above) and after relocation phase B (below)

5.2.4 Morphological evolution Schaar van Waarde/Valkenisse

Excessive transport of the disposed material to the Schaar van Waarde and/or Schaar van Valkenisse would perhaps lead to sedimentation of this flood channel and, as a result, be regarded as detrimental. In order to examine the impact of the relocation test at this location, the evolution of the profile of 2 transverse transects (transverse transect 1: Schaar van Waarde, transverse transect 2: Schaar van Valkenisse, see figure 17 for location) was monitored. Figure 24 shows the profile of transverse transect 1 graphically for the two phases of the relocation test.

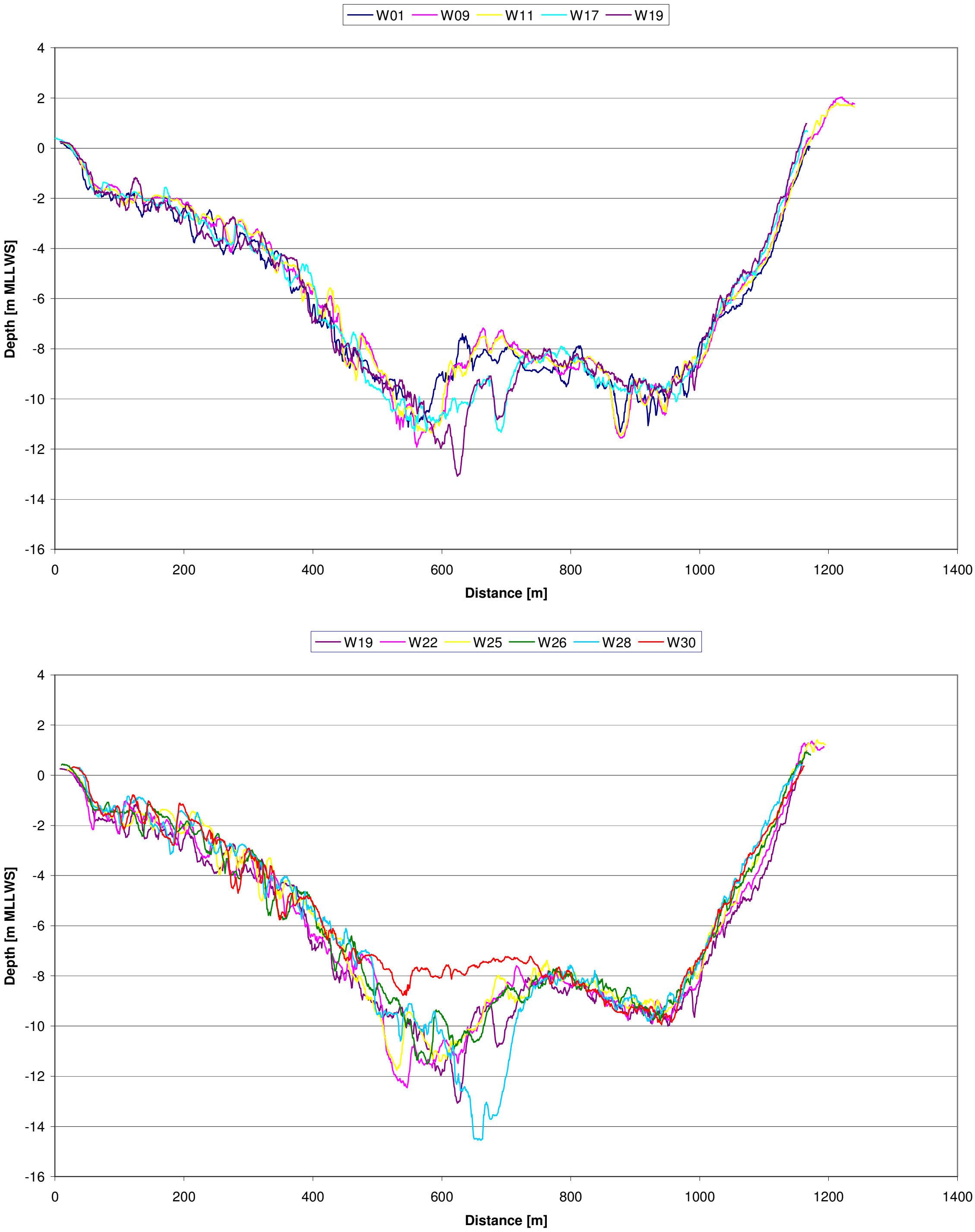
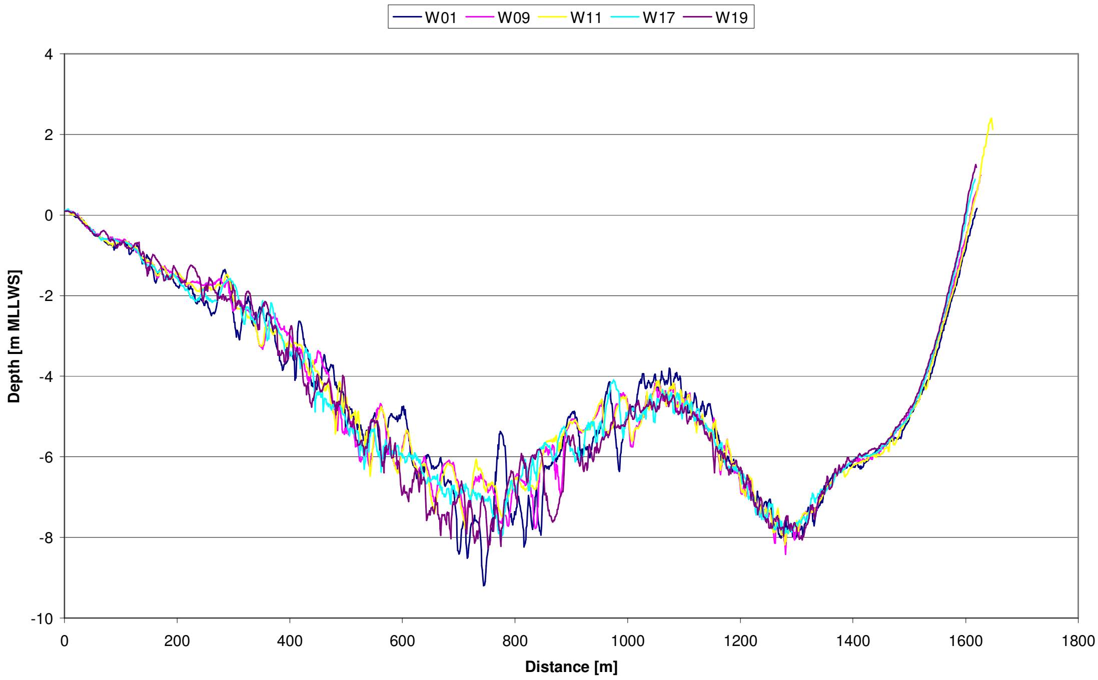


Figure 24 – Evolution north/south profile Schaar van Waarde during relocation phase A (above) and relocation phase B (below)

A deepening of transverse transect 1, caused by, among others, sand extraction, is visible between relocation phases A and B. This can be deduced from the occurrence of steep sandmining pits in the profile. After relocation test phase B, the occurrence of these pits can also be distinguished in the profile and is particularly clear during W28. This measurement was probably conducted very shortly after the sand extraction. During W30, the channel in the profile is completely filled as a consequence of the targeted relocations in the Schaar van Waarde relocation area that are also clearly visible on Figure 15.



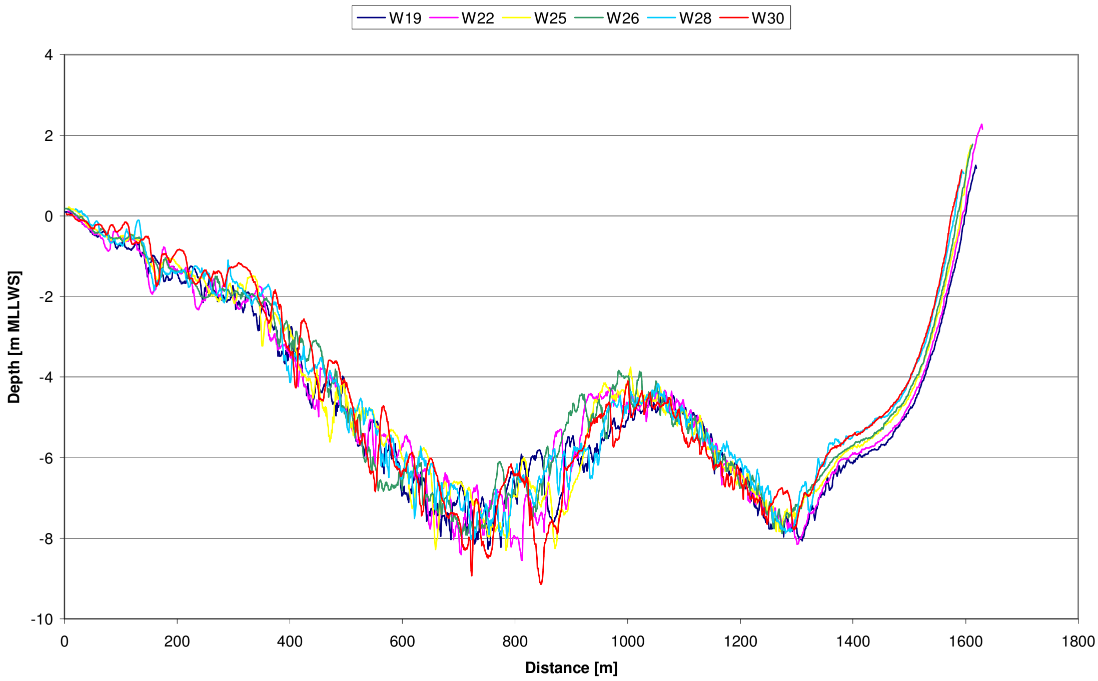


Figure 25 - Evolution north/south profile Schaar van Valkenisse during relocation phase A (above) and relocation phase B (below)

Figure 25 shows no clear changes with regard to the profile, with the exception of the south side, against the Walsoorden sandbar, where sedimentation is clearly taking place. This can also be deduced from the multibeam echo-sounder measurements.

Table 2 – Evolution profile transverse transect 1

Multibeam recording	Surface area below 0 m MLLWS	Difference compared to W01
W01	7337.8 m²	0.0 %
W09	7160.2 m²	-2.4 %
W11	7129.8 m²	-2.8 %
W17	7328.2 m²	-0.1 %
W19	7332.8 m²	-0.1 %

Multibeam recording	Surface area below 0 m MLLWS	Difference compared to W19
W19	7332.8 m²	0.0 %
W22	7128.3 m²	-2.8 %
W25	6850.0 m²	-6.6 %
W26	6815.0 m²	-7.1 %
W28	6963.9 m²	-5.0 %
W30	6283.9 m²	-14.3 %

In table 2, the calculated surface area changes (below 0 m MLLWS Walsoorden) of both wet transverse sections is given. This demonstrates that the surface area under the low water line reduces very slightly in both transverse profiles, with the exception of a small increase in transverse transect 2 right before the second phase of the relocation test. During W30 we see a significant reduction in transverse transect 1 which can be attributed to the aforementioned relocation.

The multibeam echo-sounder measurements demonstrate that this involves quite a dynamic area. The morphological developments in this area, the migration of dunes, the sand extraction and the targeted relocations ensure that the section is not constant, but is changing continuously. Measurements have demonstrated that the discharge through the Schaar van Valkenisse has increased over the past few years to the detriment of the discharge through the Zuidergat [13]. During the follow-up of the relocation test in 2004, a deepening trend of the section was noted that could be attributed to the evolution of the Schaar van Valkenisse flood channel which broke through the Valkenisse sandbar in 1990 and which has developed further over the past 15 years.

Table 3 – Evolution profile transverse transect 2

Multibeam recording	Surface area under 0 m MLLWS	Difference compared to W01
W01	7402.7 m²	0,0 %
W09	7337.7 m²	-0,9 %
W11	7322.0 m²	-1,1 %
W17	7373.4 m²	-0,4 %
W19	7509.2 m²	+1,4 %

Multibeam recording	Surface area under 0 m MLLWS	Difference compared to W19
W19	7509.2 m²	0,0 %
W22	7373.9 m²	-1,8 %
W25	7218.7 m²	-3,9 %
W26	7122.2 m²	-5,2 %
W28	7050.5 m²	-6,1 %
W30	7129.2 m²	-5,1 %

Now, however, a gradual reduction of the section can be observed. An investigation needs to look at whether this reduction can also be observed in discharge measurements. In addition to the relocation tests, relocations also took place outside the test area, in the Schaar van Waarde. This disposed material was also transported in the direction of the Schaar van Valkenisse. But it is also possible that some of the material from the relocation test was transported out of the control area. Given, however, that a large part of the transport took place from the relocation zone towards the Walsoorden sandbar and that transport towards the Zuidergat is also a possibility, the quantity of transported material from the relocation zone will be small compared to the transported material from the Schaar van Waarde relocation site. In addition, morphological developments may also be responsible for the reduction of the transverse section that has been observed.

Nevertheless, these figures show that genuine sedimentation of the Schaar van Valkenisse as a result of the relocation test has failed to occur: two weeks after each of the relocation test phases (at W11 and W22), the surface reduction of both transverse transects was less than 15% and this means that the second morphological criterion is also fulfilled.

5.2.5 Morphological analysis on the basis of volume changes

In order to determine the transport of the disposed material, the relocation site (together with the surrounding impact area) was divided up into the areas of a calculation grid. In order to simplify the interpretation of volume calculations from this grid, it is important that the grid is oriented according to the direction of sediment transport. This will allow the exchange of sediment between grid cells to be reduced to a one-dimensional phenomenon (only exchange between the grid cells according to longitudinal direction, not according to transverse direction). This is an important hypothesis and forms the basis of the morphological analysis (via sand balance).

5.2.5.1 Orientation of calculation grid

A direction that matches the direction of the flow in the area – established as a result of physical and numerical modelling [5] – was selected in order to determine grid orientation. This is also parallel to the south-eastern and the eastern edges of the relocation site (see Figure 26). The area of interest is divided into cells with a length of 250 m and width of 150 m. This enables the creation of cells that connect into the relocation sites used during the relocation test. During the analysis, an easy distinction can be made between cells which lie within and outside the relocation zone.

The grid works with 12 rows (from north-west to south-east, according to the flow) and 6 columns (from north to south, across the flow). In the direction of the Walsoorden sandbar and in the secondary flood channel, a broader impact zone was delineated around the relocation zone because sediment transport is most likely in this direction.

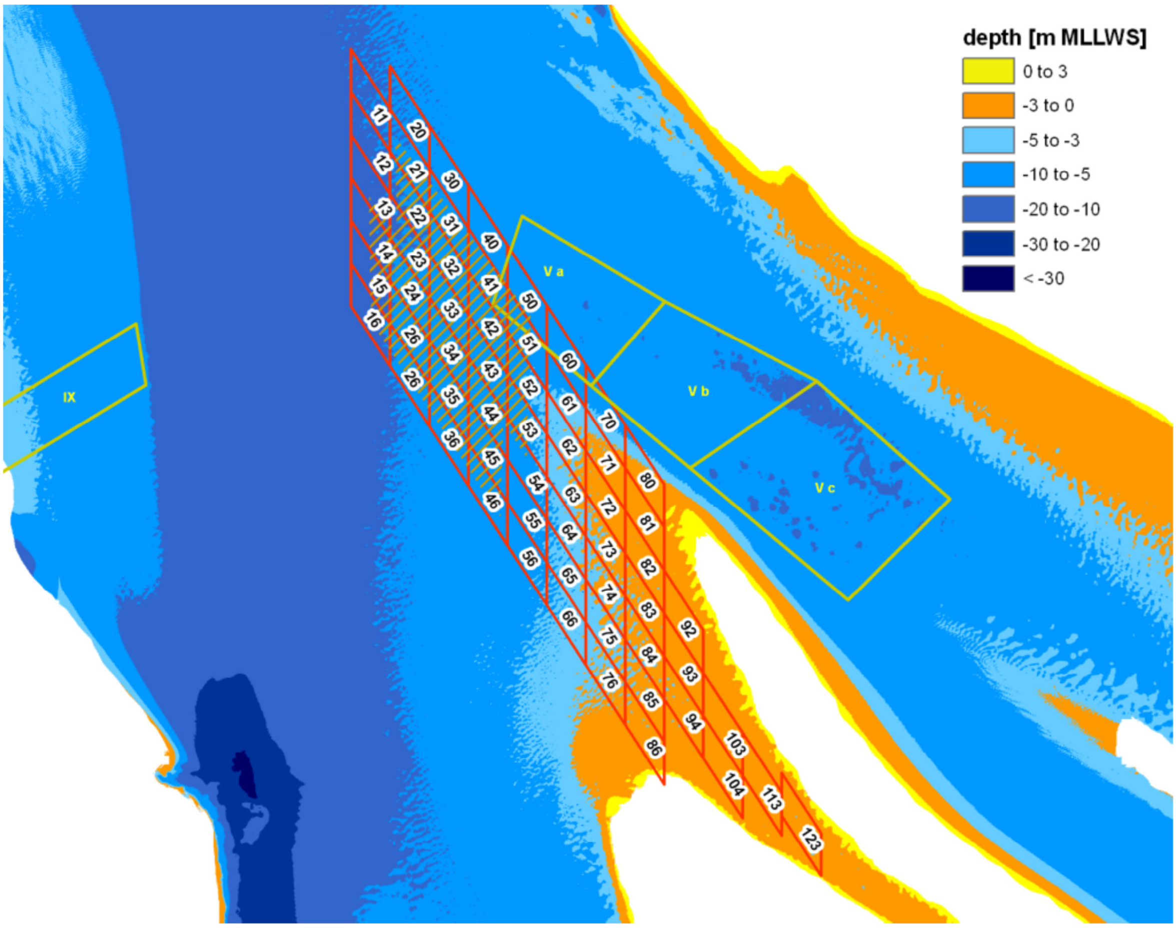


Figure 26 – Calculation areas relocation zone 2006, calculation areas: red, sand extraction areas: yellow, relocation zone: highlighted in orange

5.2.5.2 Spatial distribution of interventions

From 14 January 2006 to 11 March 2006, a total of 499,467 m³ (in situ volume) of dredged material was disposed at the location of the seaward tip of the Walsoorden sandbar. From 2 September 2006 to 17 March 2007, another 898,392 m³ (in situ volume) was disposed. Figure 27 shows the spatial distribution of the disposed quantities across the calculation grid for the two relocation phases separately (upper figures) and in total (lower figure). This demonstrates that there was spread within the relocation area but that there was a preference for the north-western part of the relocation site. This can be attributed to the greater depth that makes relocation easier there and also enables greater volumes to be discharged.

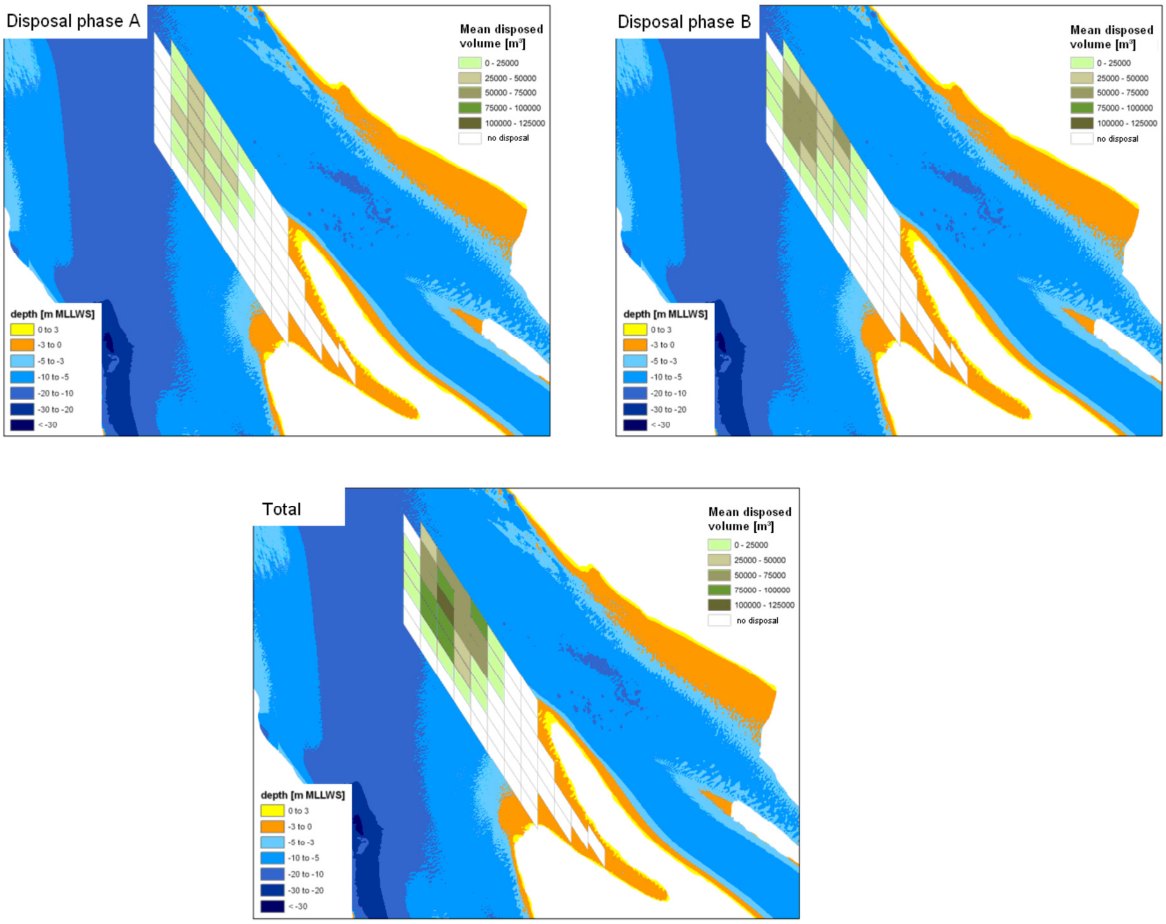


Figure 27 – Disposed volumes (hopper m³) relocation phase (above) and in total (below)

In the “Schaar van Waarde” relocation zone, in addition to the regular relocations from maintenance dredging work (in 2005 and 2007), sand was also taken from the estuary via sand extraction. Within the “Schaar van Waarde” relocation zone, there are 3 sand extraction areas which are located as stated in the sand extraction permit for the Scheldt estuary (see Figure 26). Part of the sand extraction area Va overlaps with the relocation test area 2006. The calculation grids, which cover a broader impact zone around the relocation test site, overlap the sand extraction area Va even further. In order to quantify the impact of sand extraction within the calculation grids, the sand extraction quantities were uniformly divided over the relevant sand extraction areas and, according to the size of the overlapping surface area, ascribed to the calculation areas.

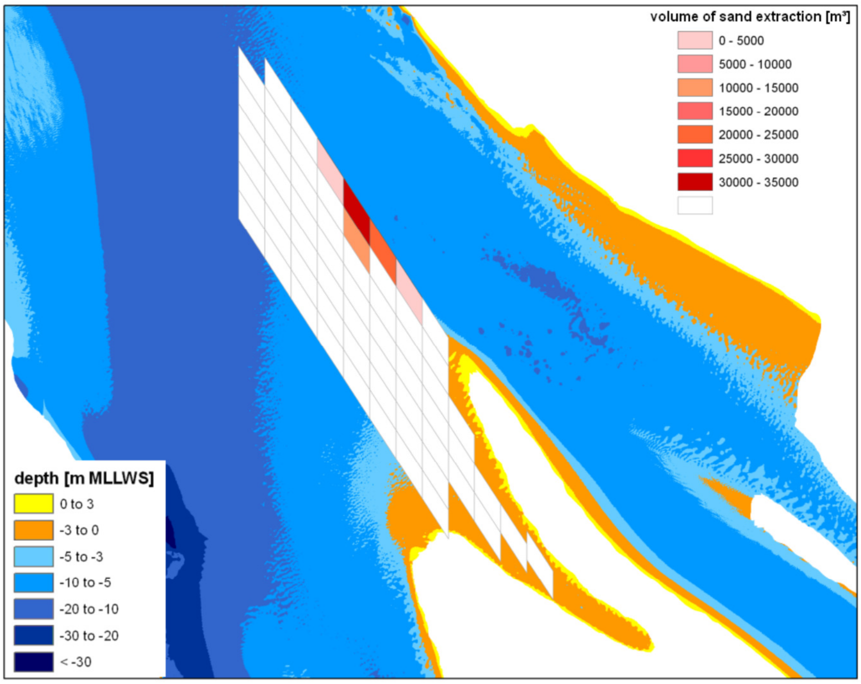


Figure 28 – Total volume [m³] of sand extraction from W1 to W30

The extracted volumes (ca. 300,000 m³), as indicated in Figure 28 for the total monitoring period, are quite limited compared to the disposed quantities. Given that these volumes, however, provide an average over the entire surface area of the sand extraction area and that sand extraction involves very localised disruption, individual sand extraction on the edge of the relocation area can lead to temporary but nonetheless significant deviations in terms of hydrodynamics and sand balance. The net volume changes, on the north-eastern edge influenced by sand extraction (compared to the total volume change in figure 27) are indicated in figure 29.

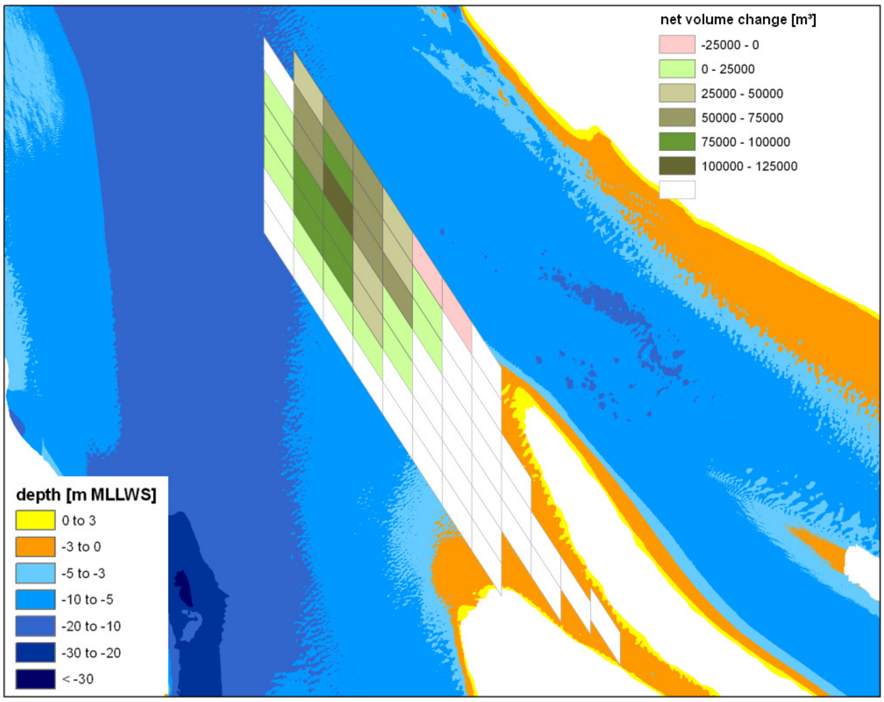


Figure 29 – Net volume change: relocation – sand extraction [m³]

Figure 30 shows the measured volume changes for the successive periods of the relocation test per calculation area. This method of visualisation splits up the consequences of the relocation test per calculation area and allows general tendencies to be distinguished, as opposed to the difference surveys where the migration patterns of individual bedforms disrupt the general overview.

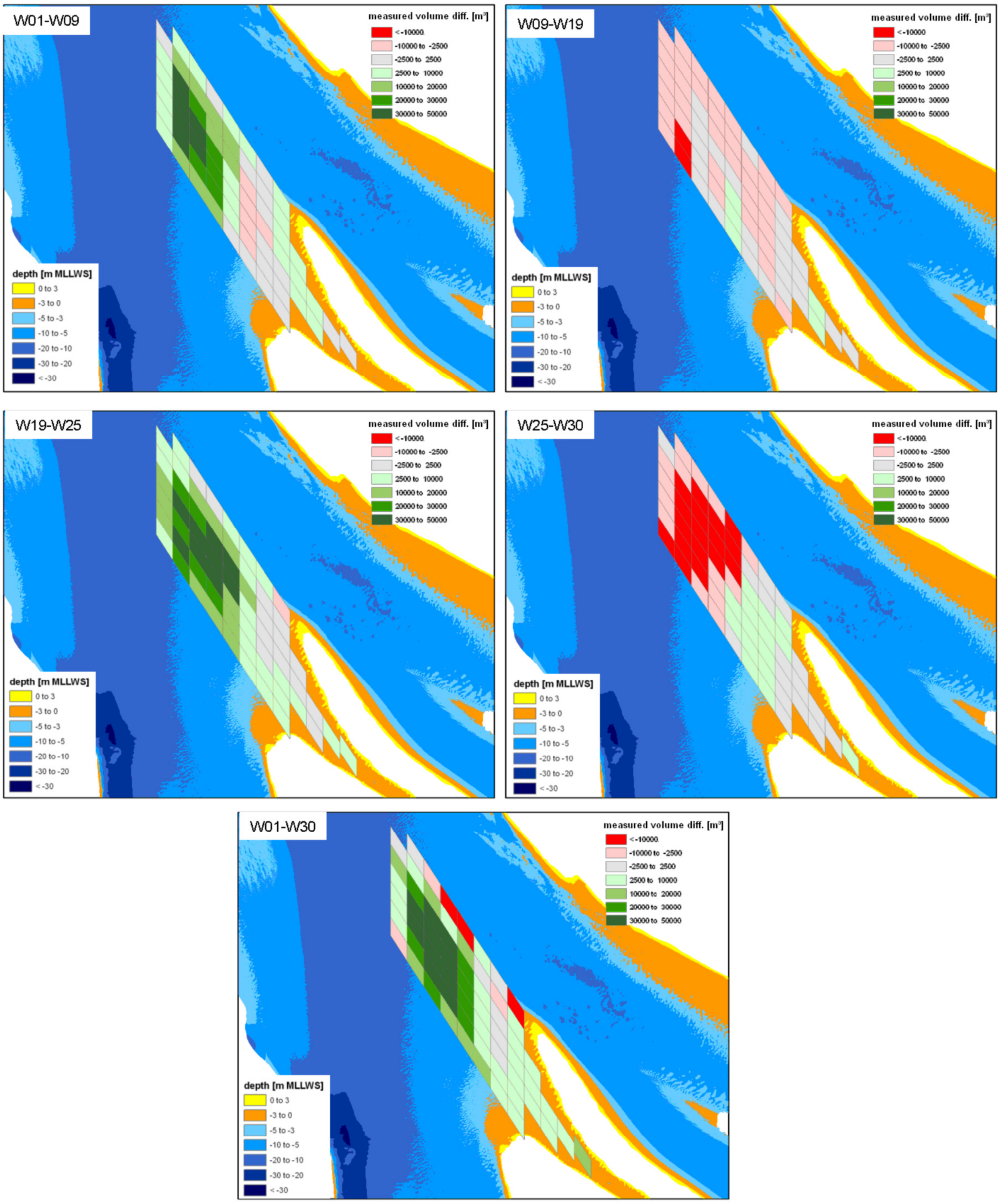


Figure 30 – Measured volume changes (multibeam echo-sounder) [m³] during and after phase A (above), during and after phase B (middle) and over the whole monitoring period (below)

During phase A (W01-W09), the volume increase in the relocation zone is clear to see and the 2004 relocation zone is also recognisable as a zone subject to erosion. In the secondary flood channel, limited sedimentation is visible. After relocation phase A (W09-W19), a volume reduction is observable in almost the entire study area and this can be attributed to the erosion of the recently disposed material and the ongoing erosion of the 2004 relocation zone.

A slight increase is visible on the section between the 2006 relocation zone and 2004 relocation zone; this points to transport towards the sandbar. The erosion of relocation zone 2004 is probably delayed as a result of the addition of material from relocation zone 2006 but this is not sufficient to positively modify the sediment balance. There is also slight sedimentation in the secondary flood channel but the sedimentation within the study area is not in proportion to the erosion. A total of ca. 200,000 m³ of the eroded material is transported outside the study area and probably taken partially towards the Schaar van Waarde and partially towards the Zuidergat.

During relocation phase B (W19-W25), the relocation was again clearly visible but the reduction in relocation zone 2004 seems to be reversed. The part of this zone that is adjacent to relocation zone 2006 now shows volume increase, the rest remains roughly constant. Local erosion has taken place on the northern sand spit and this probably means new volume loss in the direction of the Schaar van Waarde. Slight volume increase is, once again, visible in the secondary flood channel. After relocation phase B (W25-W30), relocation zone 2006 erodes and the eroded material ends up in relocation zone 2004, which is now showing slight volume increase. The synthesis figure from W01 to W30 shows an increase at the location of the relocation test site, an approximate status quo in relocation test 2004, clear sediment loss on the north side of the 2006 relocation zone and an increase in the secondary flood channel. After this relocation phase, ca. 290,000 m³ is transported outside the study area.

In order to estimate this sediment loss towards Schaar van Waarde, volume calculations were conducted on the control polygon (red line) which is indicated in Figure 31. Given that the transport nearby the relocation zone is flood dominated, it is expected that the material that does not end up in this polygon will be transported to the Schaar van Waarde. However, the volume calculations showed that both after relocation phase A and after relocation phase B, the volume loss from the polygon was greater than the volume loss from the study area. After relocation phase A, an additional 230,000 m³ disappeared from the polygon (in addition to the 200,000 m³ from the study area); after relocation phase B, in additional to the 290,000 m³ that disappeared from the study area, about 190,000 m³ extra disappeared from the polygon. Besides the erosion of the relocation, erosion on a greater scale appeared to have occurred in this zone.

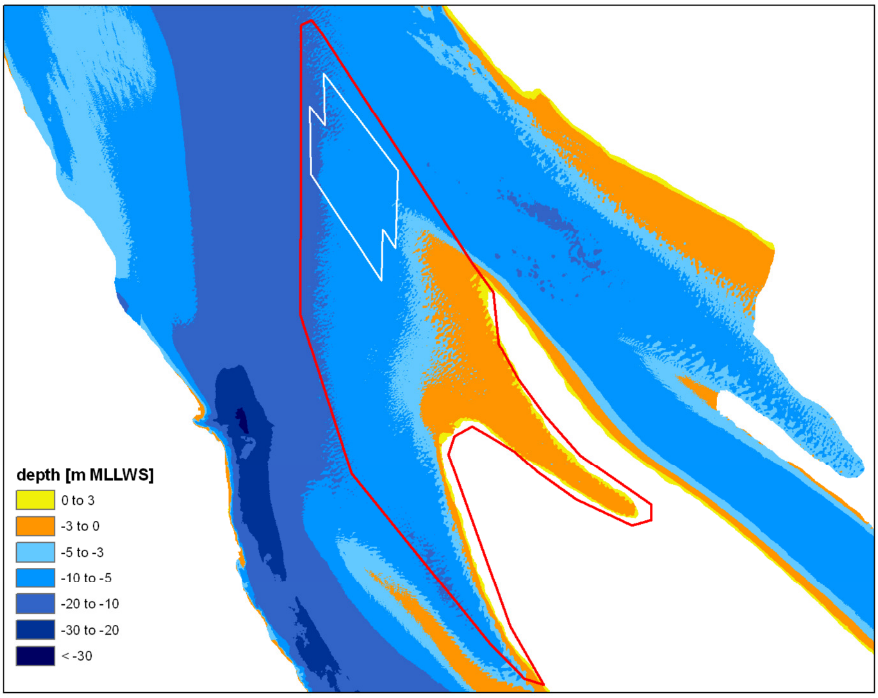


Figure 31: Polygon for volume calculations for estimation of sediment loss towards Schaar van Waarde

On the basis of an analysis of the longer term volume calculations (for detailed discussion, see Appendix E), it seems that there is evidence of a long-term erosive trend that was, however, reinforced after each relocation. As a result, it is clear that the erosion that was responsible for the erosion of the seaward tip of the Walsoorden Sandbar is still present. Some of the sediment loss in the relocation zone can, therefore, be attributed to this trend. In addition, this confirms that the relocation of material is only a curative solution here and that research also needs to be conducted in order to combat the cause of this erosion.

5.2.5.3 Volume calculations

Volume changes were calculated per calculation area on the basis of the measured multibeam data. In order to be able to present the results in a more organised fashion, the calculation areas were combined into 4 zones: seaward relocation zone 2006 (rows 1 to 3), landward relocation zone 2006 (rows 4 and 5), relocation zone 2004 (rows 6 and 7) and secondary flood channel (rows 8 to 12). It is expected that each of these zones will undergo their own, different, morphological evolution (see Figure 32).

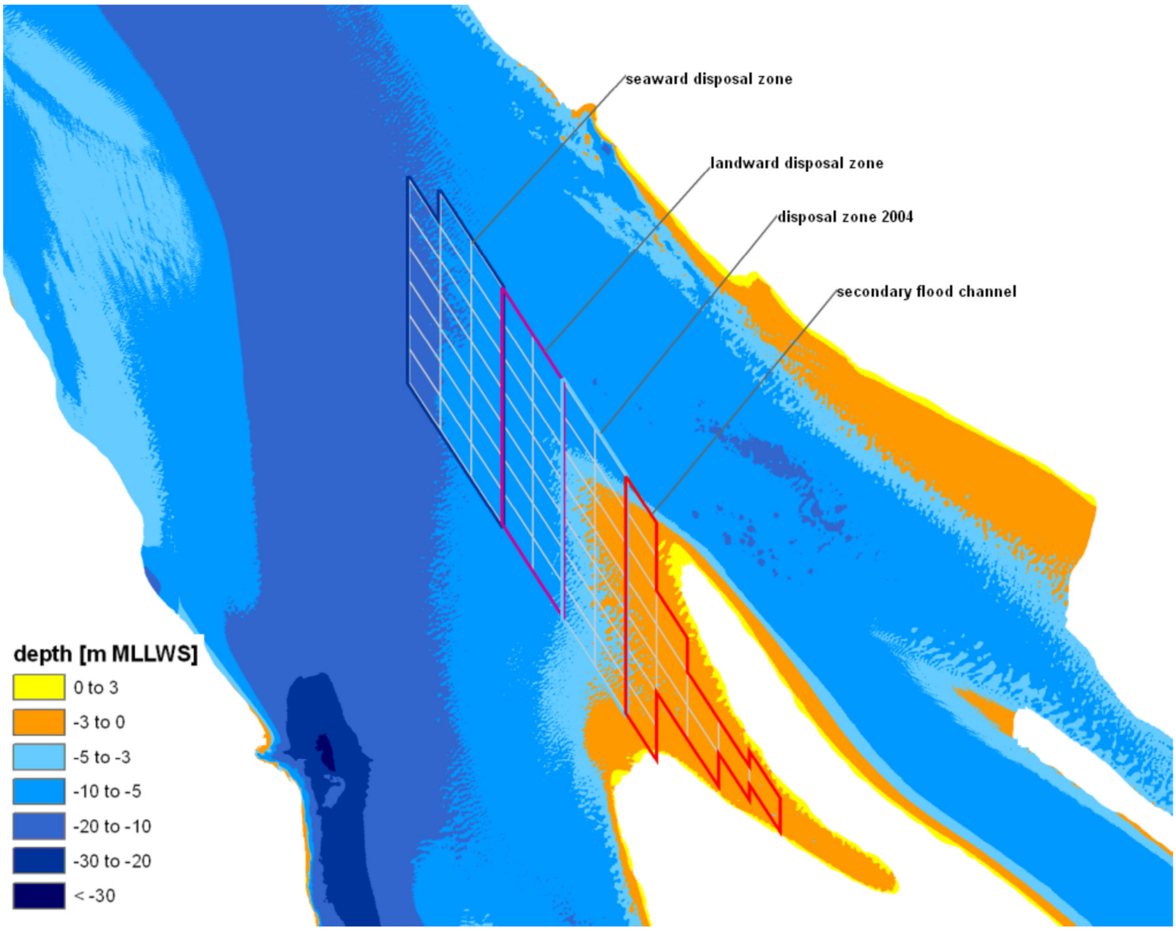


Figure 32 – division of calculation areas into calculation zones

Figure 33 shows the average volume change per surface unit for the four zones and the combination of the seaward relocation zone 2006 and the landward relocation zone 2006 (in short, the 2006 relocation zone). In order to distinguish long-term trends, a period of one year before the relocations is also included in the graph. The two parts of the relocation zone seem to develop in the same manner after relocation phase A however more material was disposed in the seaward part. During the relocation period (shown by the yellow background) the bed level systematically rised; the relocation zone eroded again somewhat after relocation. It is notable that, after the second relocation phase, the seaward zone first erodes more rapidly than the landward one and then further reduces at the same speed.

During the 2004 relocation, it had already been noted that the locally changed hydrodynamics in the relocation zone after the relocation ensured that the transported material settled at the location of the relocation zone [6]. This caused a delay in the commencement of erosion at the location of the relocation and sometimes even a temporary increase in the quantity of sand right after relocation.

Given that the last relocation in relocation phase B took place in the landward relocation zone, the delayed erosion may be explained as a result of this type of disruption to the local hydrodynamic. However, as a result of the greater depth at which this second relocation test took place compared to the 2004 relocation test, it seems unlikely that this relocation would have a substantial effect on local hydrodynamics. Natural variability within the system probably played just as great a role here. After two months, the difference in erosion speed between landward and seaward relocation zones had been eliminated.

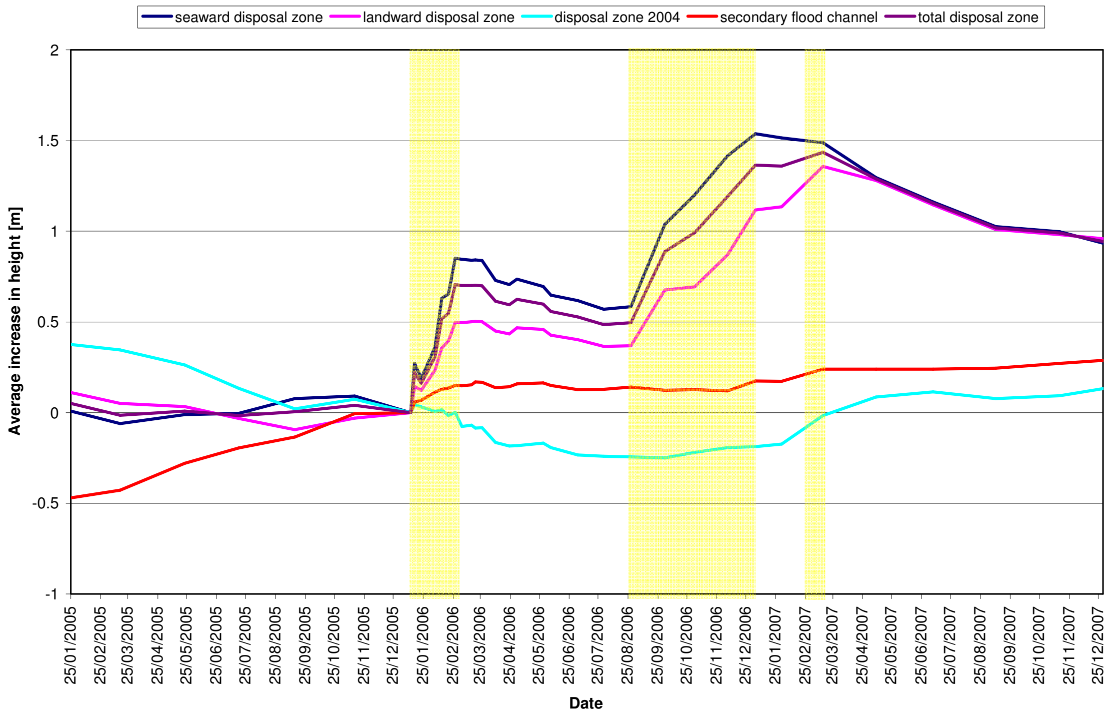


Figure 33 – Average volume changes per surface unit for the various calculation zones

It is expected that the eroded material from the relocation zone will end up in the zones that lie towards the sandbar; initially in the 2004 relocation zone and, at a later stage, in the secondary flood channel. However, after relocation phase A, the relocation zone from 2004 does not show an immediate increase but continues to diminish, just as in the period before the relocation in 2006. A constant increase is notable in the secondary flood channel. The 2004 relocation zone is probably still in an erosive phase after the relocation test of 2004, which causes the material from this zone to be transported to the secondary flood channel. This is confirmed by the constant growth that can be found here. As a result of relocation phase A, the decreasing trend in relocation zone 2004 is however gradually altered and a status quo is reached at the beginning of relocation phase B.

After the second phase of the relocation test, growth could be seen in both the 2004 relocation zone (from the beginning of 2007) and the secondary flood channel (from September 2007). Where relocation zone 2004 directly borders relocation zone 2006, this is not the case for the secondary flood channel. This explains why the increase in this latter zone will become apparent later and will probably continue for longer than in relocation zone 2004.

Figure 34 gives the average change in height per day, for column 3 of the calculation grid, for each calculation area for the successive periods of the relocation test from 2006. Column 3 runs from the relocation zone 2006 to the secondary flood channel. Given that the calculation areas are roughly oriented parallel to the direction of flow, it can be assumed that the sediment shifts largely within the same column. This choice of column 3 therefore permits analysis of sediment transport towards the sandbar over time. Given that this strip is located above the centre of the relocation zone, no account must be taken of the impact of sand extraction. The colour code in the background refers to the colour code of calculation zones in Figure 31.

During relocation phase A (shown in purple) large intensity relocation is clearly taking place in areas 23 to 43, and this is slightly less so in areas 13 and 53. Erosion is visible in relocation zone 2004 and there is sedimentation in the secondary flood channel from the eroded material from relocation zone 2004. Relocation phase B (green bars), during which larger quantities of material were being disposed of in relocation zone 2006 than during relocation phase A, shows a clearly lower intensity due to the fact that relocation was taking place over a much longer period (5.5 months) than was the case during relocation phase A (2 months). During this relocation phase, no further erosion is visible in relocation zone 2004 but sedimentation is clear and this was also evident from the analysis of figure 31. In the secondary flood channel, a lot less sedimentation is visible than during the first relocation phase.

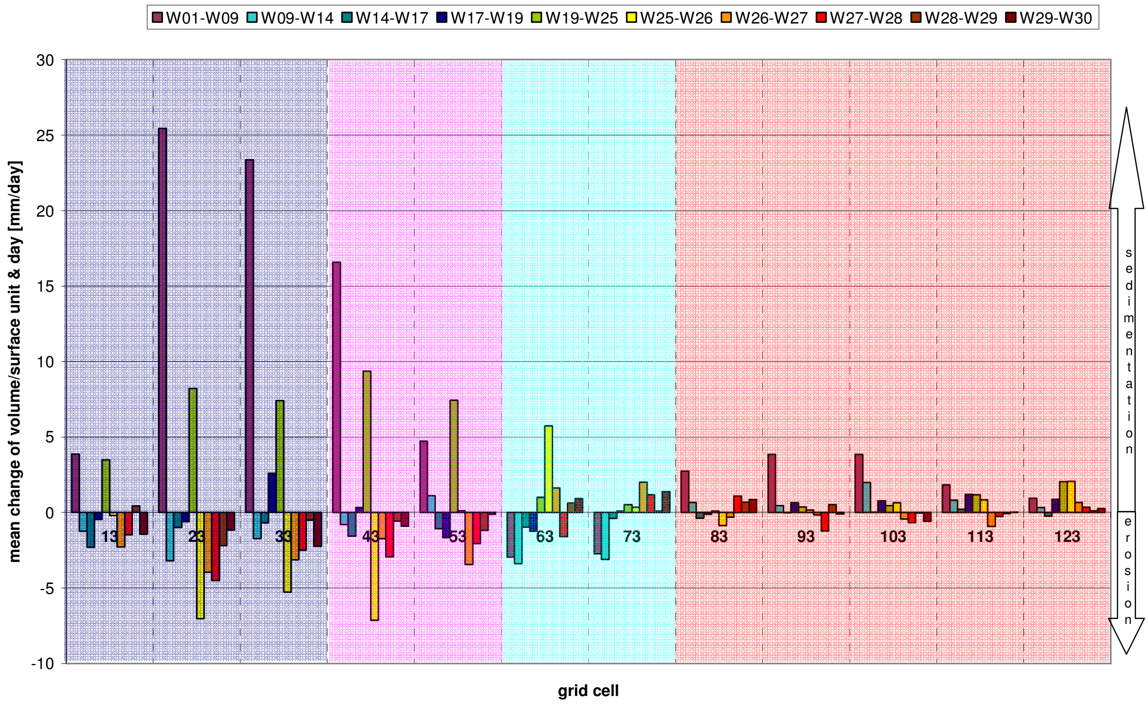


Figure 34 - Average volume changes per surface unit and per day for column 3 of the calculation grid

The areas located within the relocation zone (13 to 53) are clearly distinguishable for the periods after the relocation phase: they show erosion largly everywhere. The progress of the relocations, indicated by the difference surveys and profiles after relocation phase A (blue bars), can also be observed here: for W09-W14, the erosion first increases from the seaward to the landward side of the relocation zone and then reduces and transfers to sedimentation in area 53. In the subsequent periods (W14-W17 and W17-W19), similar, undulating progress is visible throughout the relocation zone but the maximum and minimum levels of sedimentation and erosion have shifted compared to the prior period as a result of the dunes shifting landwards. After relocation phase B (red/yellow bars) erosion takes place in the relocation zone but this reduces in time.

Areas 63 and 73, located in the 2004 relocation test area, show erosion after relocation phase A; after relocation phase B sedimentation occurs here. This confirms what is also deduced from figure 32: the erosion from the relocation test in 2004 has not yet fully come to a halt during phase A of the 2006 relocation test. After relocation phase B, the eroded sediment from relocation zone 2006 settles in relocation zone 2004, the gradual reduction in erosion over time that was noted in relocation zone 2006 is reflected here in a reduction of sedimentation over time. It is also notable that the sedimentation peak falls slightly later and is lower in area 73 than area 63 and this is logical, given the direction of sediment shift.

Sedimentation is visible in the secondary flood channel after relocation phase A and is a consequence of erosion in relocation zone 2004. After relocation phase B, the movement of material towards the sandbar can be further observed. Whereas, in relocation zone 2004, a sedimentation peak was observed in W26-W27, this occurs in area 83 in W27-W28 and in area 93 in W28-W29 and the size gradually reduces. Further away from the relocation zone, no increase is visible following the 2006 relocation test or the impact at this distance from the relocation zone is too small to be visible. Influences from the 2004 relocation test probably play a role here, including the increase in area 123, for example.

5.3 Ecological monitoring

The ecology of the study area was monitored via the CEME workgroup (Ruimtelijke Ecologie van het Centrum voor Ecologie en Mariene Ecologie/Spatial Ecology from the Centre for Estuarine and Marine Ecology) from the NIOO-KNAW (Nederlands Instituut voor Ecologisch Onderzoek/Netherlands Institute of Ecology). Within the monitoring programme, a distinction was made between sub-tidal and inter-tidal areas. The inter-tidal area is formed by the sandbars that dry during low water and are flooded by high water; the sub-tidal area borders the inter-tidal area and subsequently is always underwater. The monitoring programme for the sub-tidal area was limited to the shallow water area, given that this is ecologically more valuable.

The observations were compared with historical measurements from the MOVE (MOnitoring VErruiming Westerschelde/Monitoring Widening Westerschelde) programme as well as with the comprehensive dataset that was gathered as a result of the 2004 relocation test [11]. This comparison had to permit verification of whether an ecological break in trend could be established as a result of the 2006 relocation test.

Initially, only relocation phase A of the relocation test had been planned. The Maritime Access Division decided, at the beginning of September 2006, to move to relocation phase B. The ecological monitoring programme, however, was only focussed on relocation phase A. No specific measures had been taken at the start of relocation phase B to monitor the ecological impact of this phase. The ecological monitoring programme was further extended to 2008.

A summary is given below of the conclusions from this ecological monitoring. A comprehensive description of the results and analyses can be found in [12].

5.3.1 Sub-tidal area

The impact of the relocation test on the sub-tidal area was investigated on the basis of 3 areas: the expected impact area of the relocation test 2006 (zone I2, Figure 35), the impact area of the relocation test 2004 (zone I1, Figure 35) and a control area with depth and flow characteristics similar to those of the relocation test location 2006 (zone C1, Figure 35). Given that before the relocation test, no monitoring campaign had been conducted, a before-after-control-impact analysis was not possible. However, on the basis of the available measurements, various analyses were carried out in order to be able to assess the significance of any observed trend.

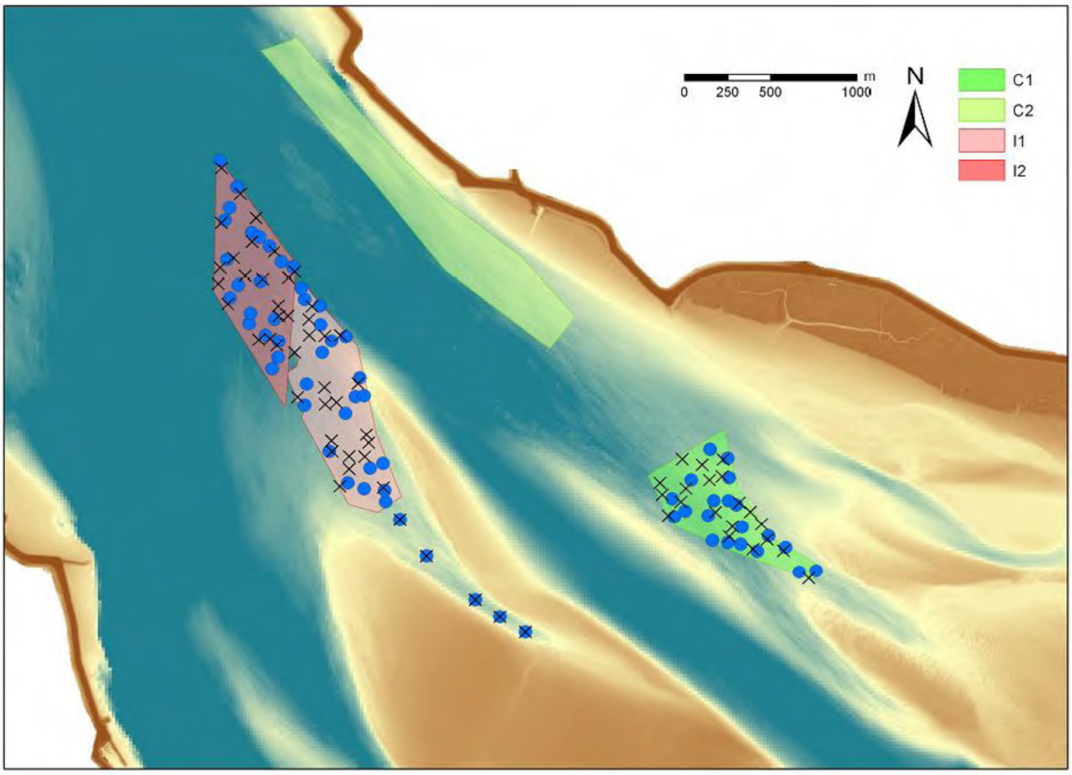


Figure 2 – Positions of the sub-tidal stations with the new impact area (relocation test location 2006, I2), control/impact area (relocation test location 2004, I1) and control area (C1). C2 was a control area for the relocation test 2004. The blue dots indicate the sampling points from May 2006, and the black crosses indicate the sampling points from August 2006.

5.3.1.1 Macrobenthos

The macrobenthos (the animals that live on the riverbed larger than 1 mm) is generally regarded as a significant indicator for monitoring changes in the estuarine environment. On the one hand, this can be ascribed to the importance of the macrobenthos in the ecosystem and as a significant component of the estuarine food chain, on the other it can be put down to the sensitivity of the macrobenthos to changes in the environment. Within each of the three areas, 20 sampling points were chosen at random. In addition, five fixed stations were selected in the secondary flood channel. Sampling was carried out twice in 2006: on 16-17 May and 28-31 August.

The samples were analysed on biomass (the total dry weight of organisms per unit of surface area), variety density (the number of individuals of one variety that were found per unit of surface area) and diversity (the number of varieties per sample).

In 2004, a BACI (Before-After-Control-Impact) analysis checked for significant consequences of the relocation test. In 2006, this approach was not possible due to the fact that relocation took place before the monitoring programme extension began. The changes in the macrobenthos and the granulometry were however followed up in time and were charted with the aid of statistical analyses.

Analysis of the measurement data proved that significant change in biomass had occurred in area I1. Figure 36 indicates that this involves a reduction. Control area C1 also demonstrated a significant reduction both in terms of biomass and density and diversity. This points to the fact that this evolution is general and is not attributable to the execution of the relocation test.

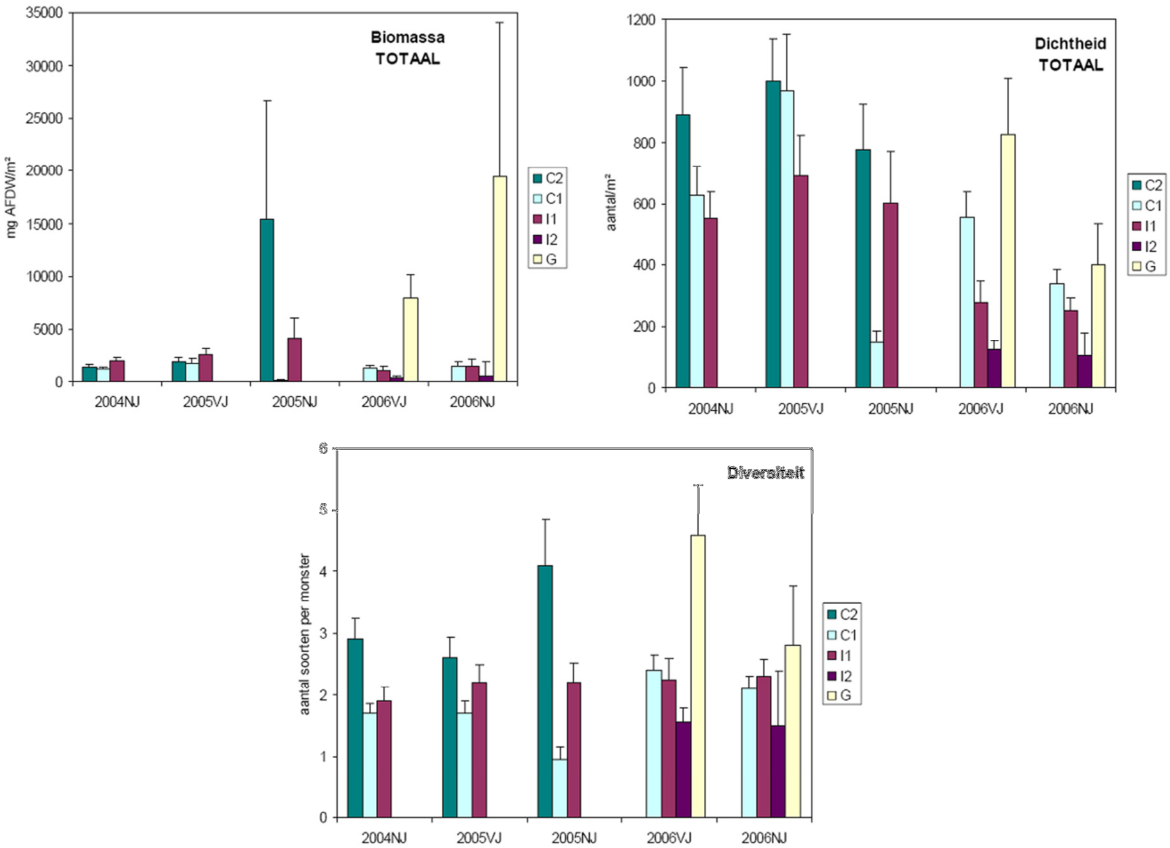
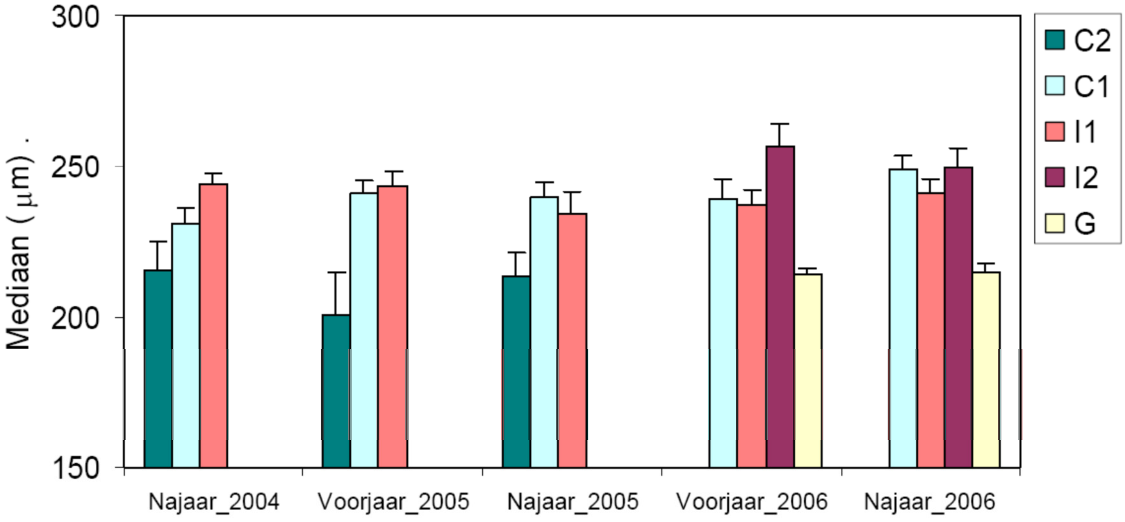


Figure 36 - Biomass, density and diversity of the macrobenthos in the sub-tidal area (G refers to samples in the channel) with standard deviation. NJ: Autumn, VJ: Spring

5.3.1.2 Granulometry of the sediment

The granulometry of the sediment was determined at the same locations as the macrobenthos. In the laboratory, a number of granular parameters were determined, including the median granule size (D50) and the percentage of mud (defined as the percentage of sediment smaller than 63 µm). Moreover, a distinction of the various samples was made between the percentage of very fine sand (between 63 µm and 125 µm), fine sand (125-250 µm) and medium-coarse sand (250-500 µm).

Analysis of sediment samples, which considered yearly and seasonal variations and the interaction between the two, indicated a significant change in mud levels for C1 and I1. Figure 37 shows a clear reduction of the mud level. This was already clear for I1 as a result of the monitoring following relocation test 2004, both in the period before and after the relocation test. It would seem as if this development towards a somewhat sandier substrate has further progressed. This analysis could not be conducted for the new relocation zone (I2) as no sampling had been conducted prior to the relocation test and measurements were only taken on two occasions.



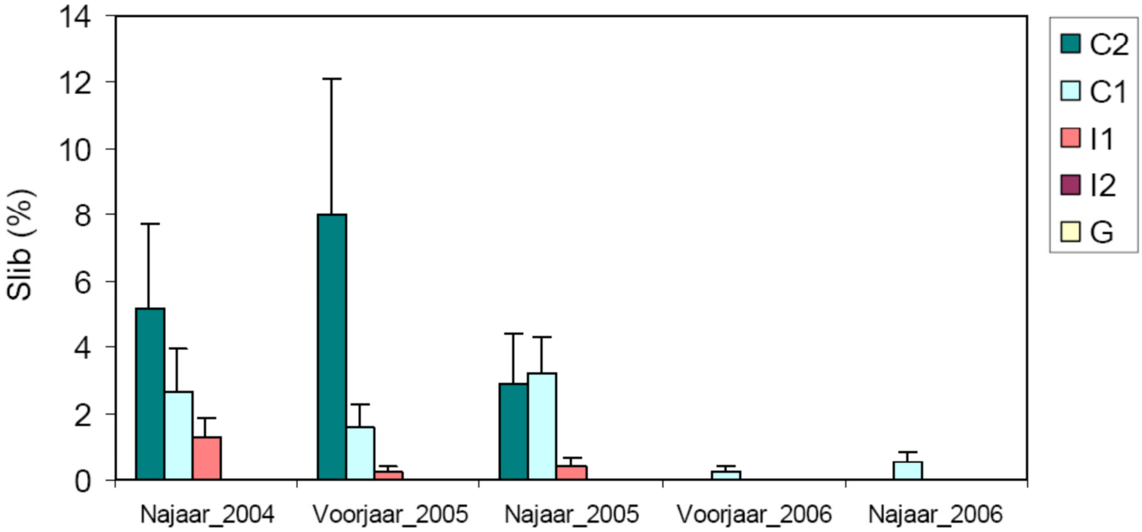


Figure 37 – Median granular size (above) and percentage mud (below) of the sediment in the sub-tidal area with standard deviation (Najaar:autumn, Voorjaar: spring)

5.3.2 Inter-tidal area

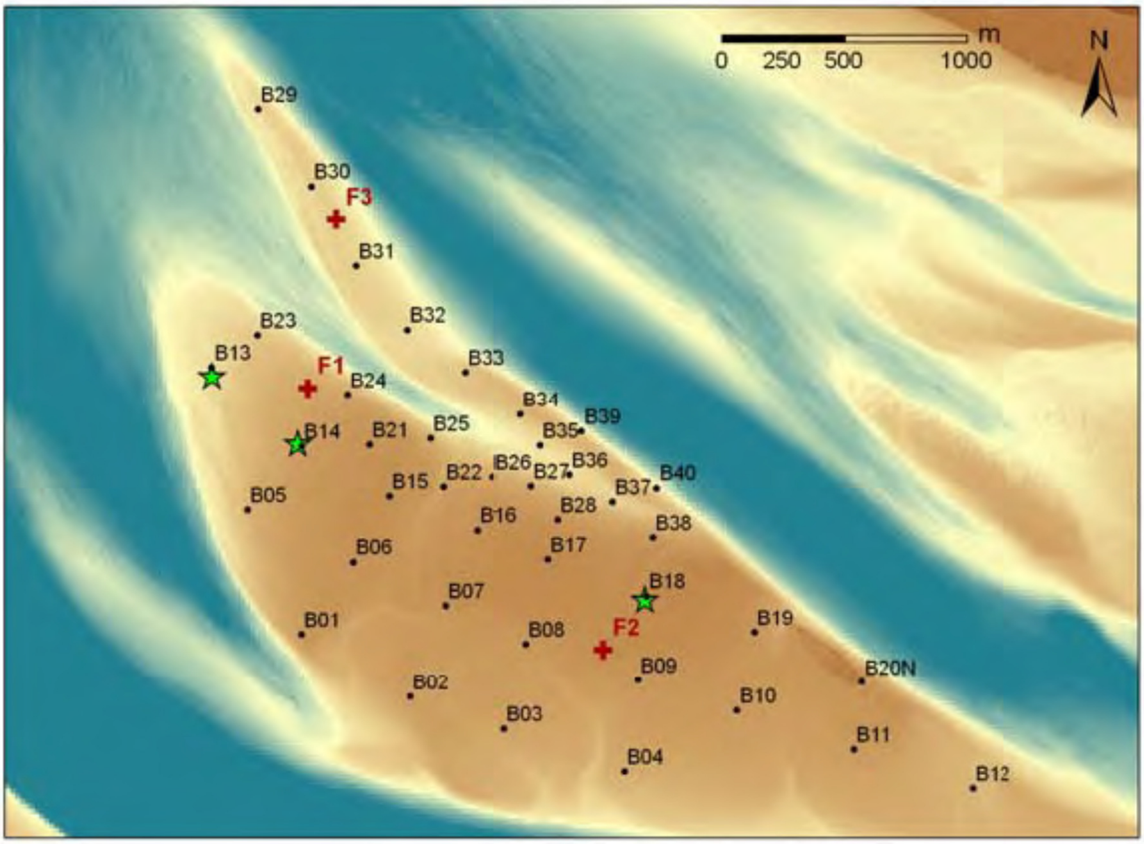


Figure 38 – Sampling locations on the Walsoorden sandbar. The three positions at which frames were placed for hydrodynamic measurements (red plus signs) and the three sedimentation/erosion plots (green stars) are also indicated.

The inter-tidal area of the Walsoorden sandbar was intensively sampled both in the monitoring programme following the relocation test 2004 and in the monitoring programme following the relocation test 2006. In order to facilitate this, 40 fixed sampling points were chosen on the sandbar with the objective of attaining maximum variability in sediment composition within these 40 samples (see figure 38). This zone was split up into 3 habitat groups on the basis of environmental factors, so that changes could be more effectively followed: the Northern Land spit (NLT), the stations lying along the edge of the sandbar (RP) and the central part of the sandbar (CP) (see figure 39). Moreover, transects were also defined. In the western part of the sandbar, the density of the stations was at its highest because most of the changes as a result of the relocation test were expected to occur here. In addition to macrobenthos and granulometry, the height of the sandbar in the inter-tidal area was also compared to measurements from the MOVE (Monitoring Verruiming Westerschelde/Monitoring Widening Westerschelde) programme.

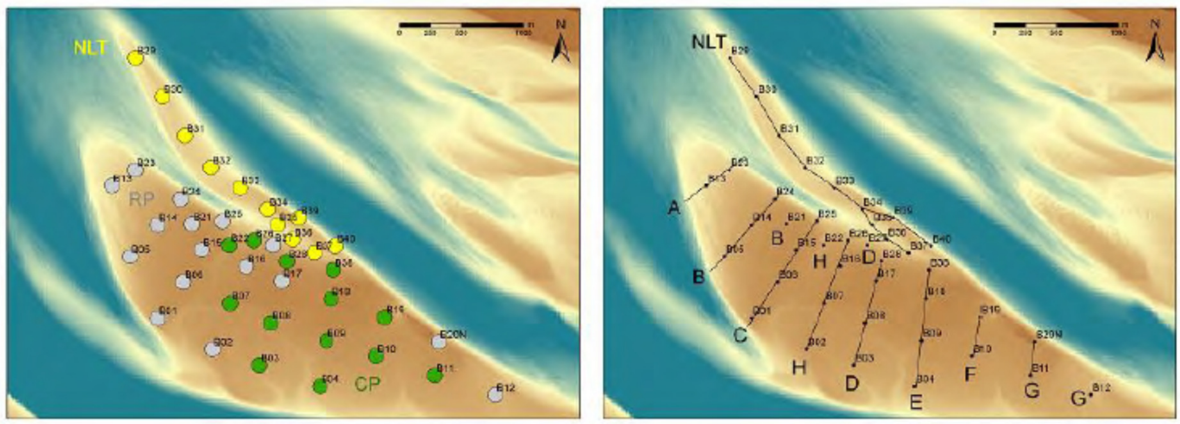


Figure 39 – Division of the inter-tidal area on the basis of habitat (left), with a subdivision in the northern land spit (NLT, in yellow), edge of the sandbar (RP, in grey) and central sandbar (CP, in green), and a subdivision in the transects A to H (right)

5.3.2.1 Macrobenthos

Figure 40 indicates the results of the macrobenthos sampling: there are clear seasonal variations, with lower biomass, diversity and variety numbers in spring than in autumn. From the tidal series graphs, it would seem that there is a slight increase in total biomass and variety number on the central part of the sandbar and a slight decrease of density of the macrobenthos on the northern land spit.

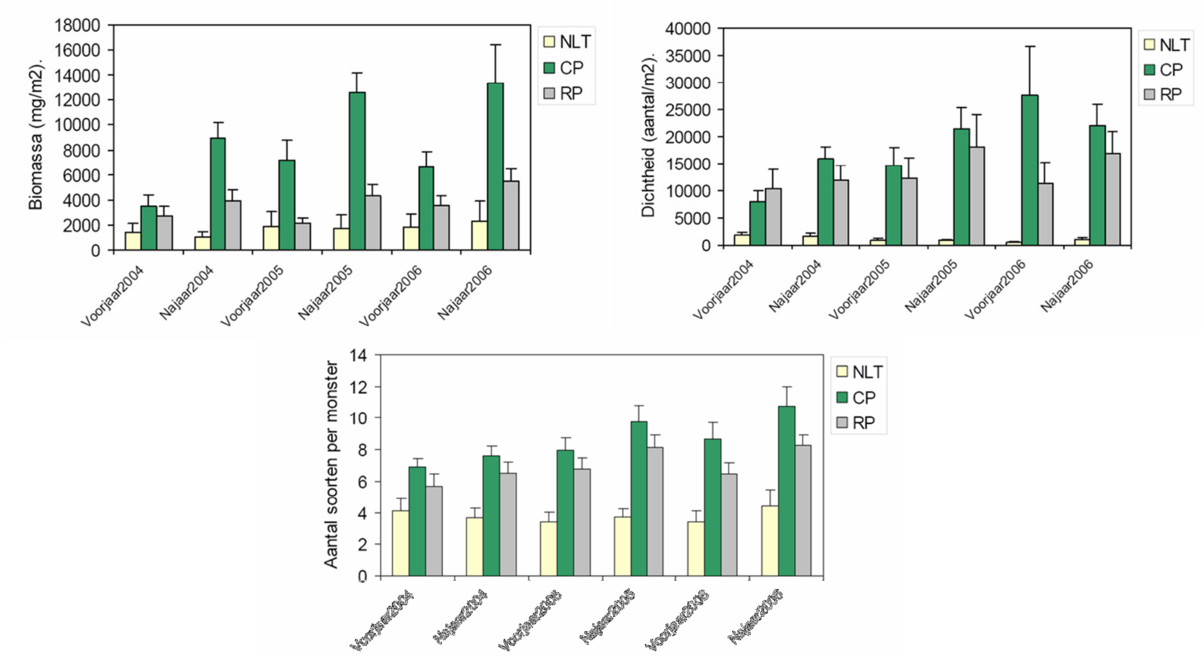


Figure 40 – Biomass, density and variety numbers of macrobenthos in the inter-tidal area with standard deviation (Najaar:autumn, Voorjaar: spring)

These trends do not occur for every variety in equal measure: analysis of the changes in the varieties at hand show that development towards a lower dynamic environment is taking place.

5.3.2.2 Granulometry of the sediment

The spatial division of the mud level and the median granular size that was found confirm the division in three inter-tidal habitats, with fine sediment on the central part of the sandbar (average D50 131 µm), coarser sediment at the edges of the sandbar (average D50 182 µm) and even coarser sediment on the northern land spit (average D50 214 µm). Figures 41 and 42 give the temporal changes in granulometry of the sediment – grouped into the 3 selected habitats. There is a seasonal variation in granular size and quantity of fine material on the central part of the sandbar and on the northern land spit. Postulating on this basis, there seems to be a long-term trend towards the refinement of the sediment on the central part of the sandbar, with an increase in the mud level and a decrease in the median granular size. There seems, however, to be a significant difference in mud level and median granular size between the three habitats but no effect between the successive years. The granulometry has therefore not significantly changed as a result of the relocation test conducted. A (weak) significant, long-term difference has been demonstrated for the mud level.

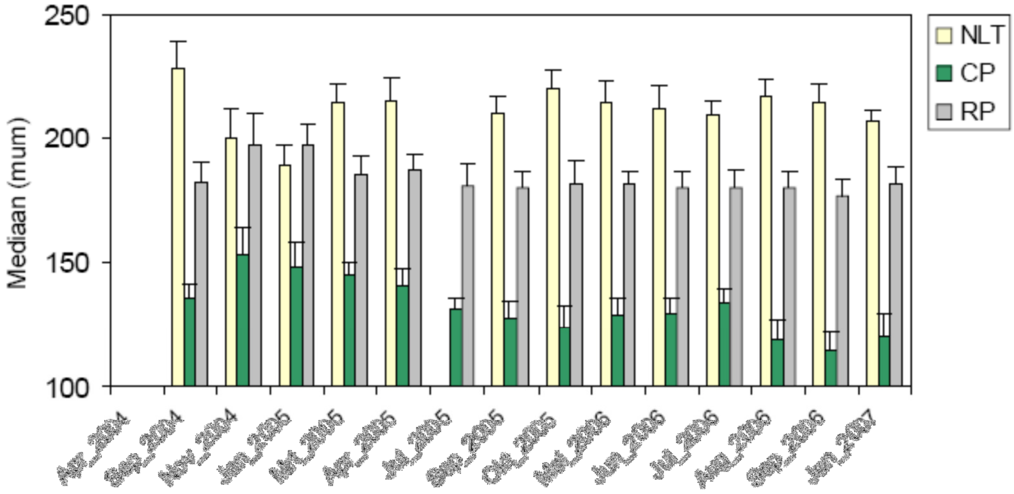


Figure 41 – Time series of median granular size of the three inter-tidal habitats with standard deviation.

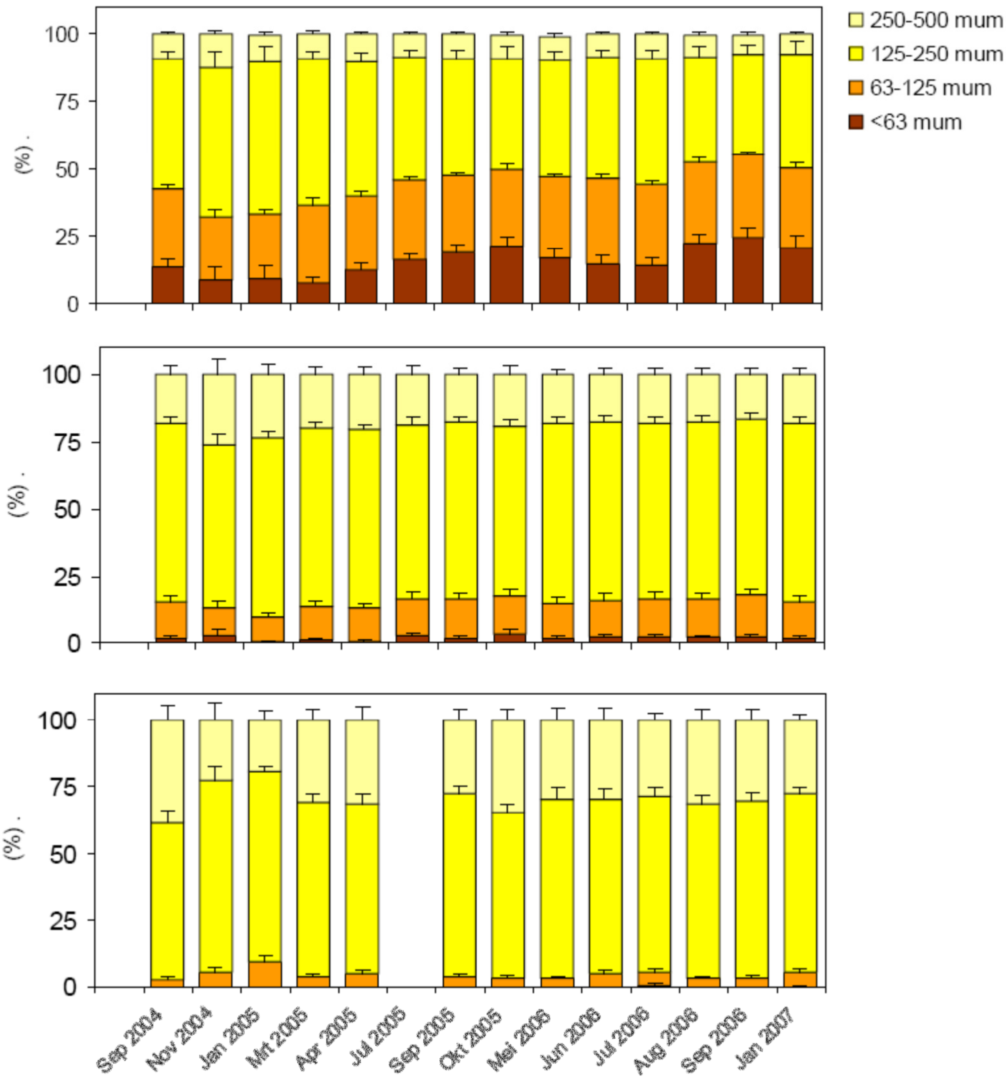


Figure 42 – changes in granulometry in the inter-tidal area, with standard deviation.
Above: CP; middle: RP; below: NLT

Figure 43 shows the differences in granulometry of the sediment averaged per transect. In terms of the median granular size, there seems to have been a slight decrease for a number of transects. For transects A and B, this corresponds to a slight increase in very fine sand and a decrease in medium sand, for lines H and D, this corresponds to an increase in mud and very fine sand and, for line F, this corresponds to an increase in mud and a decrease in very fine sand and fine sand. The mud level shows huge fluctuations over time. Analysis of the measurement date again points to significant differences between transects and seasons, but no significant differences over the long-term.

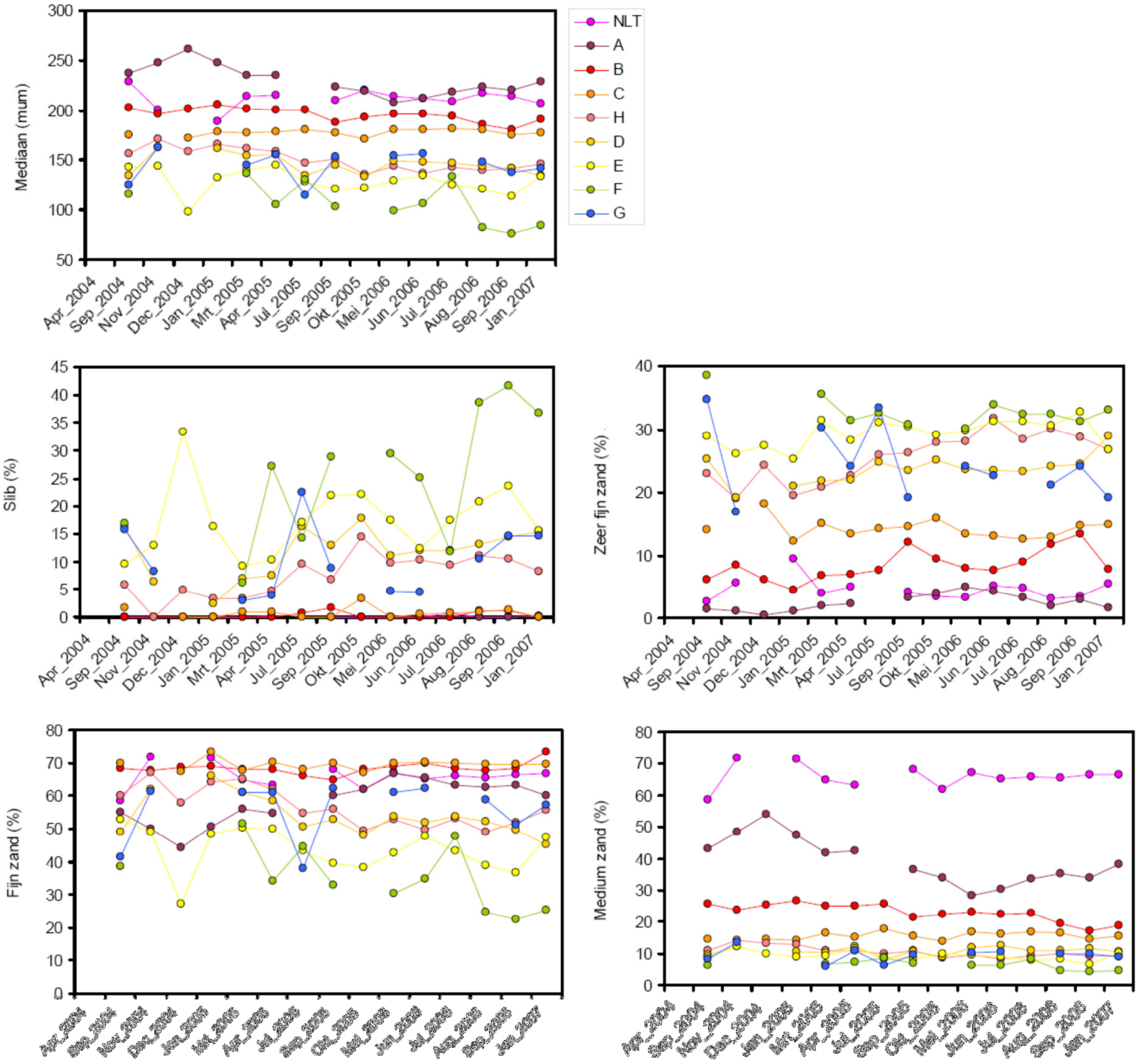


Figure 43 – Time series of median granular size SD50, percentage mud, very fine sand, fine sand and medium sand for the different transects

5.3.2.3 Height of the sandbar

The height of the sandbar was measured in 2 ways. The first method used a sedimentation erosion bar. At 3 locations on the sandbar, the absolute height at various times was measured compared to a rod that was fixed at a constant height. The results of these measurements are given in Figure 44. In the western part of the sandbar, an erosive trend of 3.3 to 3.6 cm/year was noted, while the central part of the sandbar is increasing in height by about 2.5 cm/year. The measurements in these 3 stations indicate a continuation of the trend that was also clear from the MOVE measurements. There is, therefore, no impact on the elevation of the sandbar as a result of the relocation test.

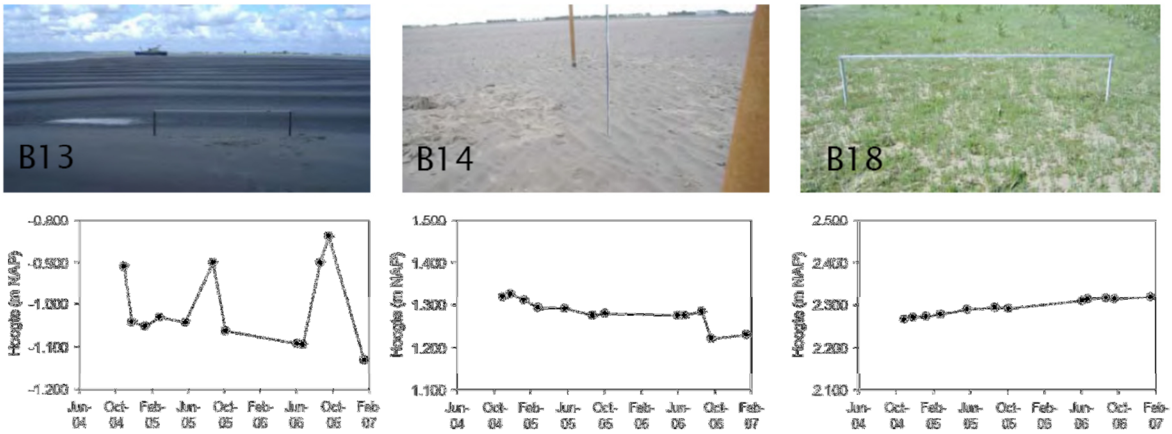


Figure 44 – Sedimentation-erosion measurements at station B13, B14 (both western part of sandbar) and B18 (central part of sandbar)

In addition to the results of the sedimentation-erosion bar at 3 locations on the sandbar, the height of the entire sandbar was measured using laser altimetry. This measurement (see Figure 45) showed that the largest part of the Walsoorden sandbar is not changing significantly. Only the edges are changing and the central part of the sandbar seems to be increasing in height. These changes, however, cannot be directly linked to the relocations. The height increase in the central part of the sandbar, in particular, is a long-term phenomenon that was also demonstrated by the MOVE measurements.

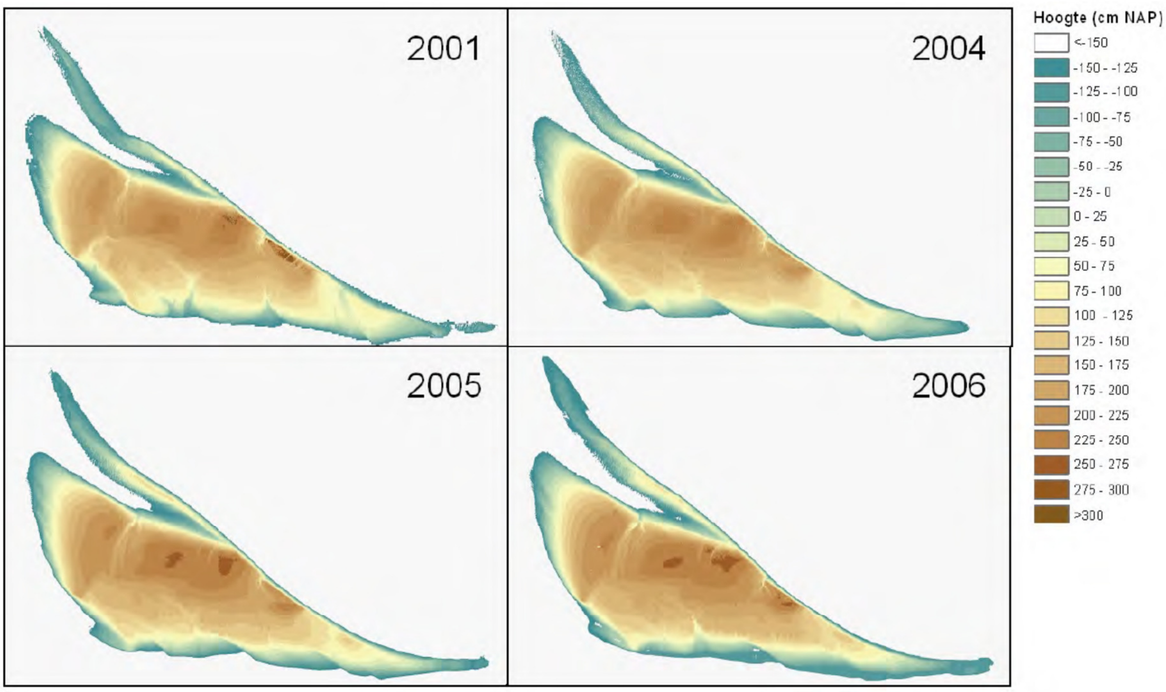


Figure 45 – Height of the Walsoorden sandbar from laser altimetry, based on data from Directorate-General for Public Works and Water Management (2001 and 2004) and Eurosense (2005 and 2006). Circumference is the -1.5 m NAP contour.

5.4 Monitoring conclusions

On behalf of the Technical Schelde Committee, morphological and ecological experts that were involved in the project drew up criteria for the relocation test 2004 on the basis of which the success or failure of the relocation test could be assessed (see Chapter 4). Given that no specific criteria were drawn up for the 2006 relocation test, the 2004 criteria were used once again to assess the relocation test. These criteria have already been dealt with in the previous analyses; this paragraph will provide a short summary of the results.

5.4.1 Morphological criteria

Table 4 gives the assessment of the relocation test on the basis of the morphological criteria drawn up. The previously set criteria are compared with the observed effects.

Table 4 - morphological criteria of the relocation test

Set in advance	Observed
Criterion 1: Stability of the disposed material	
Maximum 20% of the total disposed quantity may have left the relocation site 2 weeks after completion of the relocation test. **Between 20 and 40% of the material may disappear from the relocation site, if extreme conditions have led to this.** **Over 40% loss of material will be regarded as a failure of the test.**	Two weeks after the end of relocation phase A, there is evidence of a limited material decrease (0.5%), two weeks after relocation phase B no measurements were conducted but around 2 months after the relocation test, around 15% of the material had disappeared. After 2 weeks, therefore, less than 20% had disappeared.
Criterion 2: Sedimentation of Schaar van Valkenisse	
Maximum 15% of the transverse profile of the Schaar van Valkenisse (at the location of the bar that now lies at the head of the Schaar) may have been occupied by sand 2 weeks after the completion of the relocation test.	Two weeks after the end of relocation phase A, there is a limited decrease (2.8% and 1.1% respectively) of the transverse profile for the 2 selected transverse sections. Two months after relocation phase B, there is a decrease of 7.1% and 5.2% respectively. This is, however, attributable to the targeted relocations that took place in the Schaar van Waarde.

On a morphological level, it can be concluded that the relocation test has been a success. The material seems to be stable despite stability being slightly lower than the relocation test of 2004. This was, however, an expected effect given the different relocation technique that was used in 2006 and the more dynamic conditions in the deeper relocation location. The movement of the material is also largely in the direction of the sandbar. The results of the feasibility study are therefore confirmed in this in situ trial.

5.4.2 Ecological criteria

Table 5 gives the assessment of the relocation test on the basis of the ecological criteria drawn up. The previously set criteria are compared with the observed effects.

Table 5 – Ecological criteria of the relocation test

Set in advance	Observed
Criterion 1: Height increases on the Walsoorden sandbar	
On 25% of the sandbar more than 4 cm, on 50% of the sandbar more than 2 cm or on 100% of the sandbar more than 1 cm will be regarded as a problem.	Fixed point measurements indicated that the western edge of the sandbar was undergoing a reduction in height of 3.3 to 3.6 cm/year; the central part of the sandbar is increasing at a rate of 2.5 cm/year. This trend is also clear from the MOVE measurements.
Criterion 2: Changes to percentage of inter-tidal mud	
On 50% of the sandbar more than 40% change in the mud level or on 100% of the sandbar more than 20% change in the mud level will be regarded as a problem.	The granular analyses from samples taken on the sandbar indicate that there is no significant deviation as a result of the relocation test. Seasonal deviations in the mud level were clear from the measurements.
Criterion 3: Changes in inter-tidal macrobenthos	
The density, biomass and diversity of the inter-tidal macrobenthos may not deviate from the long-term trends.	No significant deviations of the inter-tidal macrobenthos were observed as a result of the relocation test. A shift towards a lower dynamic environment was observed but this was also the case in the control zone and cannot, therefore, be attributed to the relocation test.

In conclusion, we can suggest that the relocations involved in this trial did not lead to significant, detrimental ecological consequences. Large-scale effects on the macrobenthos as a result of the relocation test in 2006 seem to have been avoided. This cannot, however, be stated with certainty in relation to the relocation location because no prior sampling was carried out in order to characterise the natural habitat and macrobenthos community.

In the inter-tidal area, diversity in terms of the variety of the macrobenthos increased. The composition of the macrobenthos also changed significantly. The development seems to correspond to the central part of the sandbar gradually elevating and taking on lower dynamic characteristics. The changes seem to relate to the long-term development of the sandbar and not to the relocation test. No significant changes in sediment composition were observed.

Because the disposed material is only transported towards the sandbar slowly, the morphology of the sandbar is also not influenced. The positive developments towards a more low-dynamic environment on the central part of the sandbar were not caused by the relocation test. Such positive consequences were also not expected, given the relatively limited scope of the relocations. Given that there are, however, no negative consequences in relation to the relocation test, this can nevertheless be regarded as successful.

6 Translation into policy and management

As a result of the success of the relocation tests in 2004 and 2006, it was decided that this new relocation strategy, whereby dredged material is disposed of along sandbar edges, would be expanded to multiple locations in the Westerschelde. In the context of the project to widen the channel, following the environmental impact report [14] and the relevant assessments, it is concluded that the method whereby the applied dredged material (and some of the maintenance dredged material) is disposed along the edges of the sandbar is the most environmentally-friendly alternative. Further research [15] was conducted in order to ascertain how this strategy could be implemented within future dredging and relocation policy.

Four locations along the sandbar edges in the Westerschelde were proposed as future relocation locations for dredged material. The new relocation strategy creates new, ecologically valuable areas without endangering the multi-channel system. As a result, this makes a proactive contribution towards the aims for the estuary from the long-term vision.

7 Recommendations

The analysis of the relocation test focussed on the zone around the actual relocation test site and the zone between the relocation area and the Walsoorden sandbank. The second relocation test, in particular, however demonstrated that some of the disposed material is transported outside this zone. The high dynamics (hydro en morphodynamics) here makes the impact of the transported material difficult to investigate. It is therefore recommended that a better insight is obtained into the morphodynamics in the Schaar van Waarde/Schaar van Valkenisse zone – in order to estimate the possible transportation away from the relocation test zone – and the Zuidergat/Hansweert sill – in order to chart the bar's sedimentation process.

During the relocation test in 2004, the hypothesis was put forward that the relocation test disrupted the hydrodynamics in the system in such a way as to prevent the expected erosion from starting immediately, as a result of what temporary settling of the material was noted. During the relocation test of 2006, this trend was not so clearly observed. Given the fact that relocation here took place at greater depth and in a more dynamic area, a relocation volume of the same size at this location will have a less significant impact on the local dynamics. Given, too, that the implementation of this relocation strategy within the ordinary dredging and relocation routines would involve much larger volumes, a recommendation is made to further investigate the impact of relocations on the local morpho- and hydrodynamic conditions.

Even though both of the relocation tests in the zone in front of the Walsoorden sandbar can be regarded as successful, attention must not waver from the fact that this has involved very limited relocation quantities which amount to just part (20%) of the relocation quantities that are necessary for full reconstruction of the sandbar point. In order to implement the proposed strategy, extensive monitoring is still required. Initially, this would be to see whether the results remain positive with larger volumes of disposed material and, on the other, to evaluate a number of desired effects that could not have been checked during the relocation tests due to its limited nature. These are:

- Improved distribution of the tidal flow between the ebb and flood channel;
- An increase of the velocities in secondary channels adjacent to the Walsoorden sandbar, particularly above the Hansweert sill. This will allow the self-eroding capacity to increase and dredging efforts to be reduced;
- Enrichment of the shallow water and inter-tidal areas with finer granular fractions as a consequence of a reduction of the flow speeds in these areas;

In addition to alternative relocation strategies, attention must also focus on morphological dredging and the management of hard boundaries (dikes, hard layers) in the estuary in order to manage the Scheldt estuary in a morphologically balanced manner.

8 References

[1] RIKZ, “Westerschelde, stram of struis?”, 1997

[2]] Port of Antwerp Expert Team (PAET), “Improving navigation conditions in the Westerschelde and managing its estuarine environment – How to Harmonize accessibility, safetyness and naturalness”, January 2001

[3] Port of Antwerp Expert Team (PAET), “A strategy for managing the Westerschelde’s morphology – An addendum to the final report”, May 2001

[4] Port of Antwerp Expert Team (PAET). “Alternative Dumping Strategy. The Feasibility of Morphological Dredging as a Tool for Managing the Westerschelde.”, September 2003.

[5] Flanders Hydraulics Research, “M678/1 Alternative dumping strategy Walsoorden – Results physical & numerical modelling”, November 2003

[6] Second Opinion, “An alternative strategy for dumping in the Scheldt estuary – Comments of the expert team”, October 2003

[7] Waterbouwkundig Laboratorium Borgerhout, “Alternatieve Stortstrategie Westerschelde – Proefstorting Walsoorden – Eindevaluatie Monitoring”, April 2006

[8] Waterbouwkundig Laboratorium Borgerhout, “Advies voor de stortstrategie toegepast bij de uitvoering van de storting nabij de plaat van Walsoorden in 2006”, December 2005

[9] Waterbouwkundig Laboratorium Borgerhout, “Beneden Zee- en Westerschelde – Morfologische analyse van de bagger- en stortintensiteitsdata van 2000 tot en met 2005”, June 2007

[10] Waterbouwkundig Laboratorium Borgerhout, “Habitatmapping - deelrapport 1: classificatie op basis van bodemvormen en hydrodynamica”, January 2009

[11] NIOO, “Alternatieve stortstrategie voor de Westerschelde – Ecologisch Monitoringsprogramma proefstorting Walsoorden – Rapport 11/11”, March 2006

[12] NIOO, “Alternatieve stortstrategie voor de Westerschelde – Voortzetting monitoringsprogramma proefstorting Walsoorden – Lot 2 – Ecologische monitoring”, June 2007

[13] RIKZ, “Monitoring van de effecten van de verruiming 48’-43’-38’ – MOVE Hypothesen – document 2003 – MOVE Rapport 7”, June 2003

[14] Consortium Arcadis-Technum (CAT), 2007. “Hoofdrapport Milieueffectrapport - Verruiming vaargeul Beneden-Zeeschelde en Westerschelde”, October 2007.

[15] Waterbouwkundig Laboratorium Borgerhout, “Determinatieonderzoek plaatrandstortingen” – 3 deelrapporten, 2008.

Appendix A – Summary of soundings conducted

Summary of the available topobathymetric data (multibeam echo-sounding)

Sounding	Date of sounding	Zone
W01	12/01/2006	B
W02	16/01/2006	B
W03	23/01/2006	B
W04	6/02/2006	A
W05	13/02/2006	B
W06	20/02/2006	B
W07	27/02/2006	B
W08	6/03/2006	A
W09	16/03/2006	B
W10	20/03/2006	B
W11	27/03/2006	B
W12	10/04/2006	A
W13	24/04/2006	B
W14	2/05/2006	A
W15	29/05/2006	B
W16	6/06/2006	A
W17	4/07/2006	A
W18	31/07/2006	A
W19	28/08/2006	A
W20	2/10/2006	A
W21	2/11/2006	A
W22	6/12/2006	A
W23	4/01/2007	A
W24	31/01/2007	A
W25	15/03/2007	A

W26	9/05/2007	A
W27	7/07/2007	A
W28	10/09/2007	A
W29	15/11/2007	B
W30	7/01/2008	B

Appendix B – Evolution of depth contours

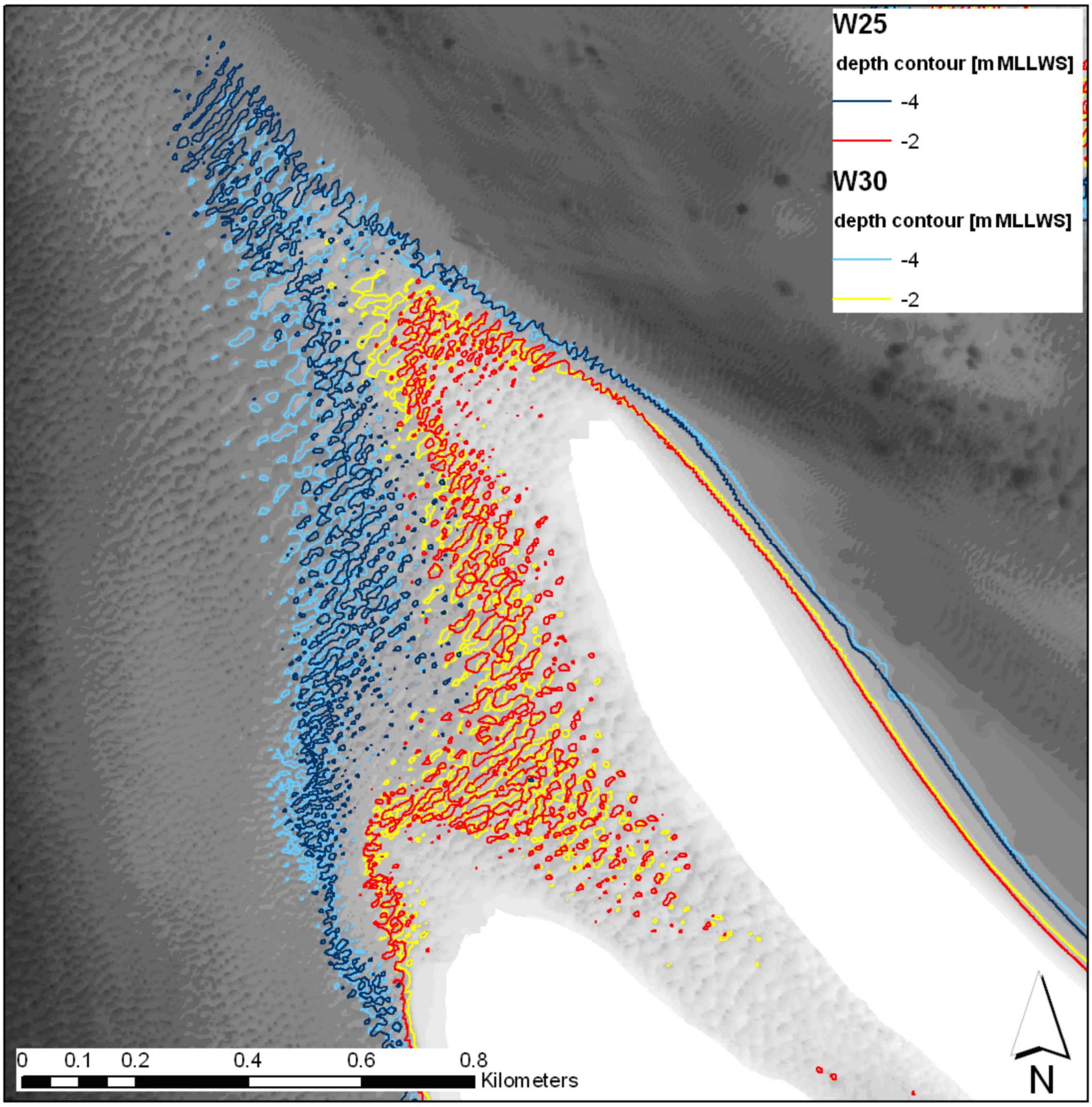


Figure B 1 : Movement of depth contours -4 and -2 MLLWS from W25 to W30

Appendix C – Dune development

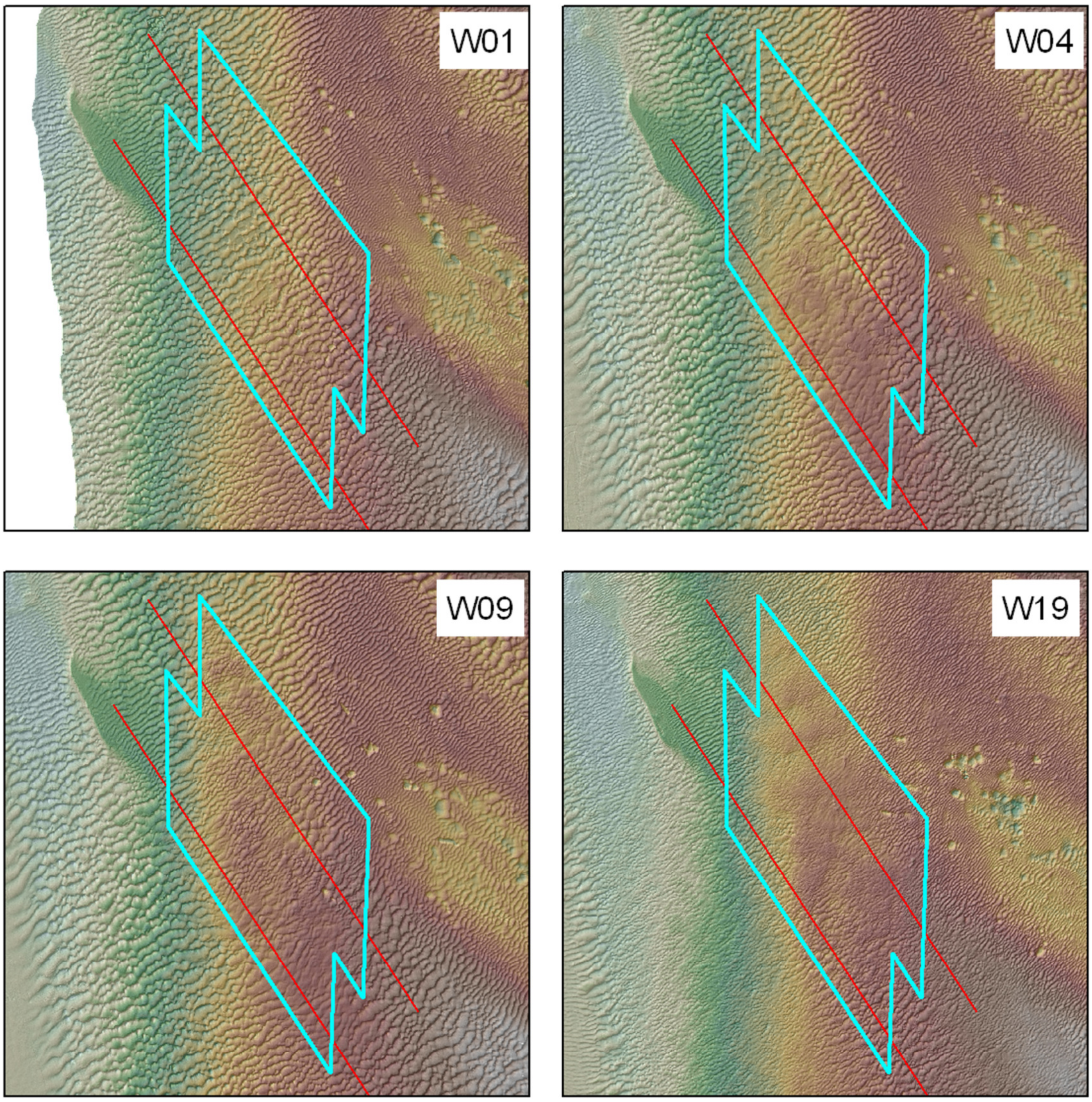


Figure C 1: Shaded view of dune development after relocation phase A of relocation test 2006

Appendix D – Derived characteristics of bedforms

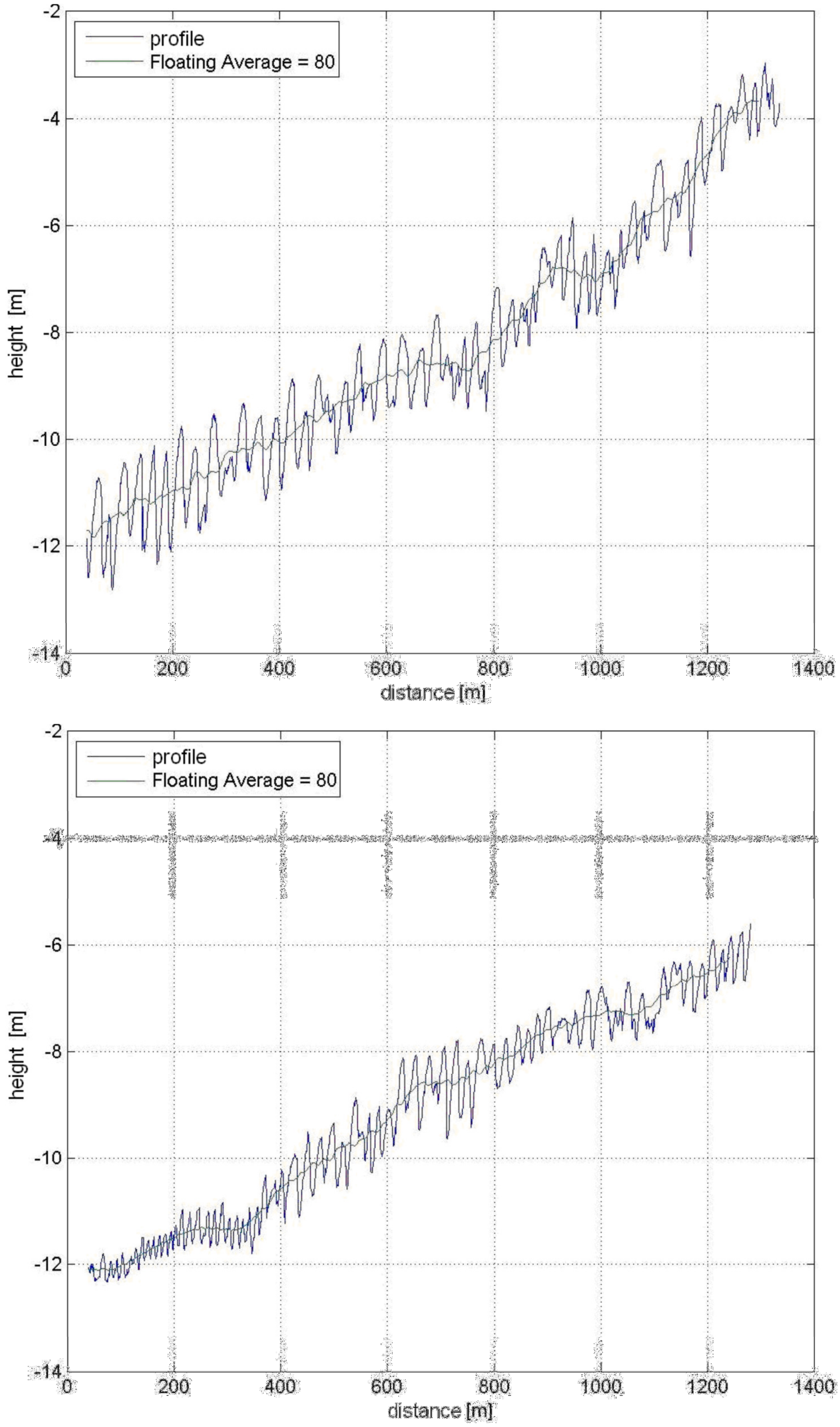


Figure D 1: Profile and Floating Average for W01 (above: north, below: south)

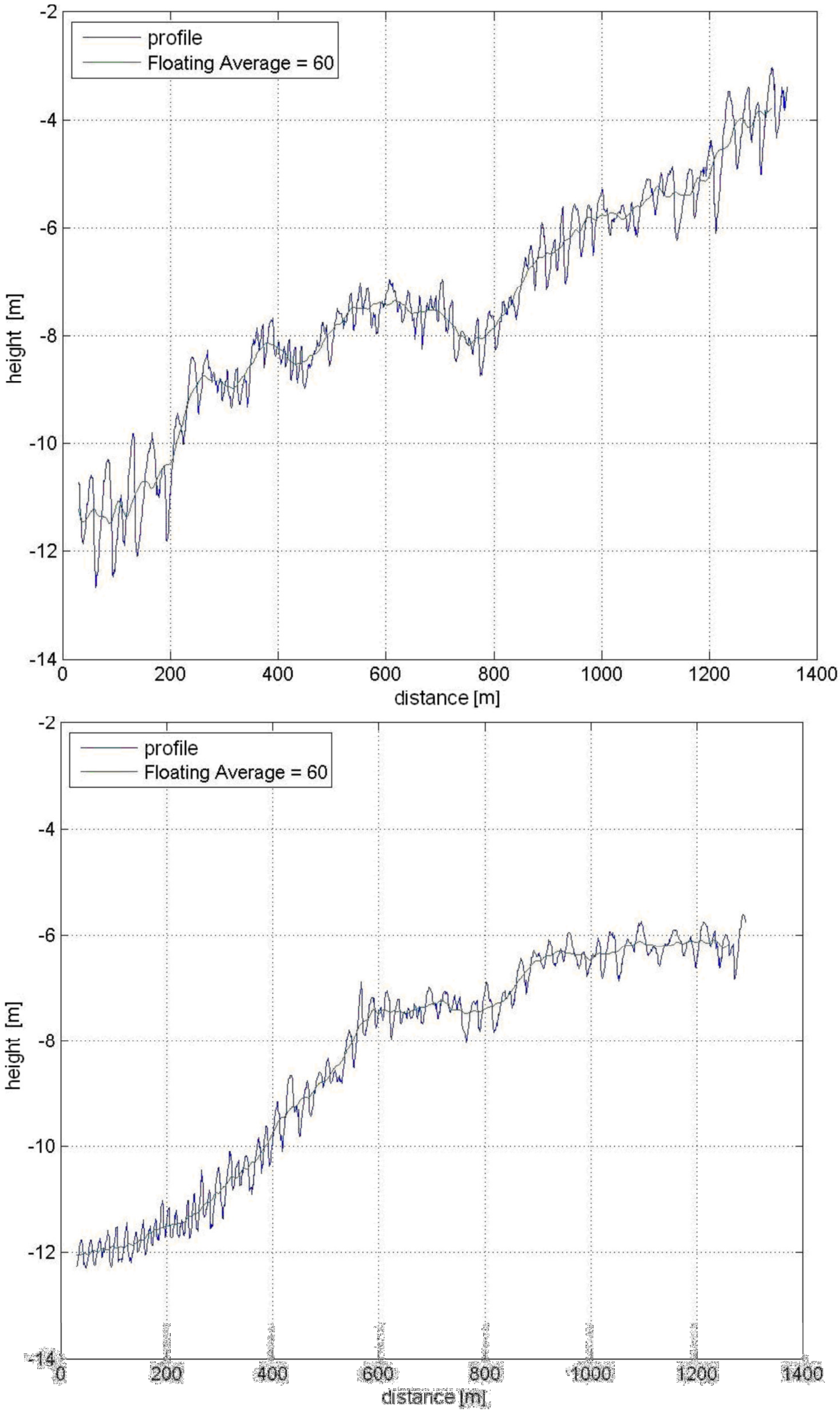


Figure D 2 : Profile and Floating Average for W09 (above: north, below: south)

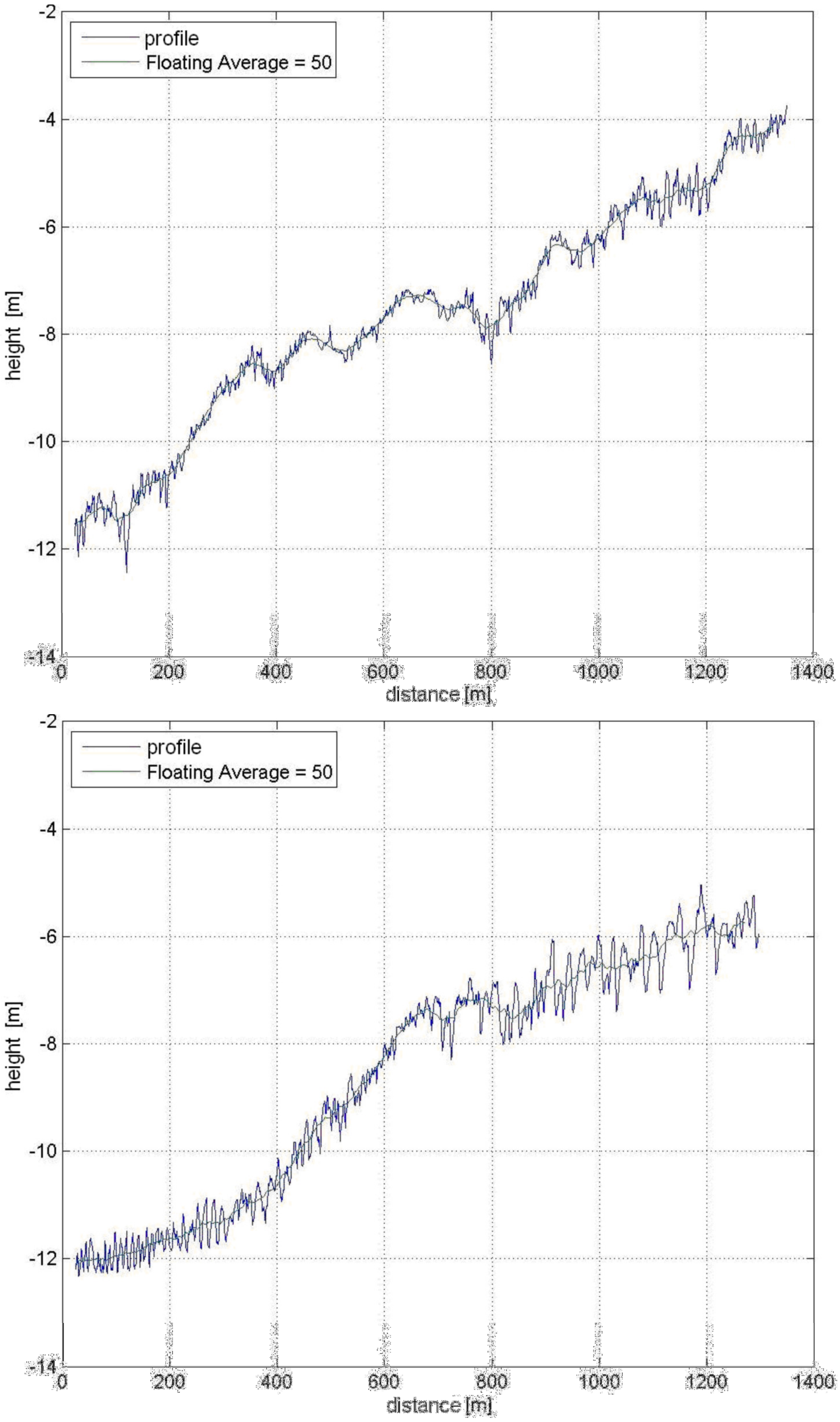


Figure D 3 - Profile and Floating Average for W19 (above: north, below: south)

Appendix E – Long-term morphological evolutions

Additional volume calculations were carried out in order to verify whether the volume loss after relocation phase A and relocation phase B, indicated in the polygon in the figure below, forms part of a long-term development. For each year, from 1990 to 2007, volume changes were calculated on the basis of the topobathymetric data from Directorate-General for Public Works and Water Management. In addition to these volume calculations, additional difference surveys were also drawn up per six-year period. Figures 1 to 3 indicate the difference surveys from 1990 to 1996, 1996 to 2002 and 2002 to 2007 respectively.

Figure E1 (1990-1996) indicates significant erosion within the polygon which also shows erosion on the tip of the Walsoorden sandbar. Erosion of over 4 m over a six-year period has been observed both along the northern side (secondary flood channel) and the southern side. The northern sand spit rotates in a clockwise direction, with sedimentation along the edge of the Schaar van Waarde and erosion along the edge of the secondary flood channel.

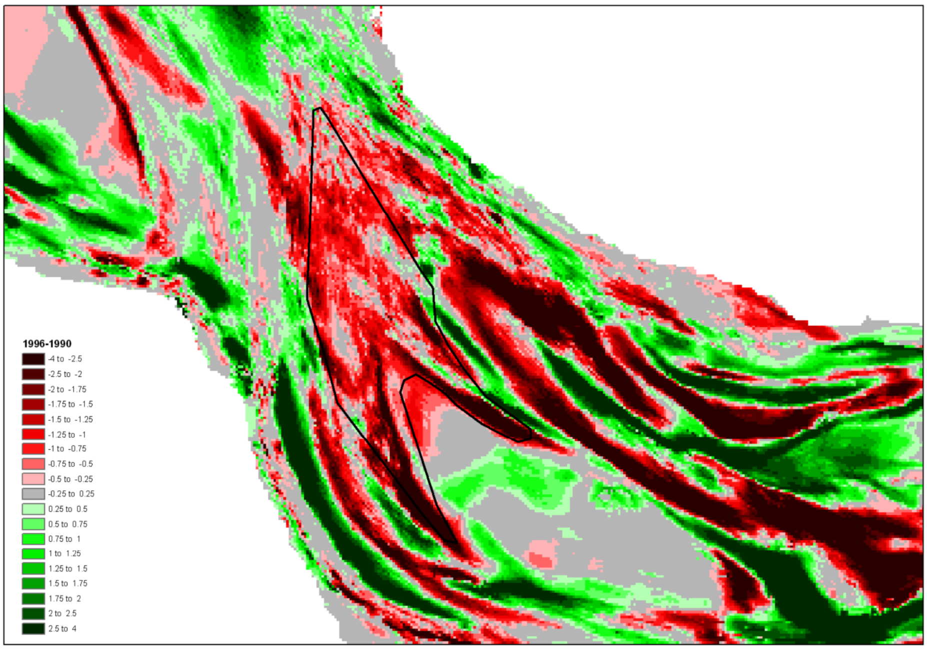


Figure E1: Difference survey between 1990 and 1996

In the subsequent period (figure E2 - 1996-2002), erosion along the northern side of the sandbar tip is less pronounced and there is no sedimentation in the secondary flood channel. In the southern part of the control polygon, both directly alongside the sandbar point as well as further away from it, erosion remains clear, as it is on the seaward tip of the Walsoorden sandbar itself. The ‘turning’ of the northern sand spit is also visible, with erosion on the sand spit itself and settling in the direction of the Schaar van Waarde.

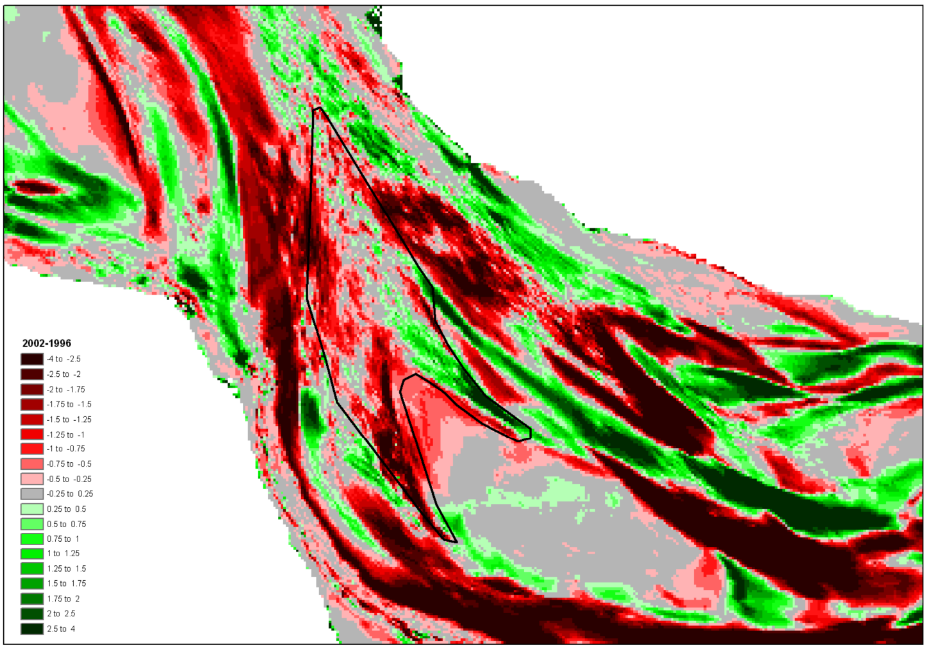


Figure E2: Difference survey between 1996 and 2002

Between 2002 and 2007 (figure E3), the period in which both the relocation test 2004 and that of 2006 took place, there is clear sedimentation at the location of both relocation zones. There is also clear elevation in the secondary flood channel. On the southern side of the polygon, erosion is still visible but it is less pronounced. It is worth noting that the tip of the Walsoorden sandbank is showing less or no erosion, probably as a result of protection of the sandbar point by the relocation (and transport of the material from the relocation zone).

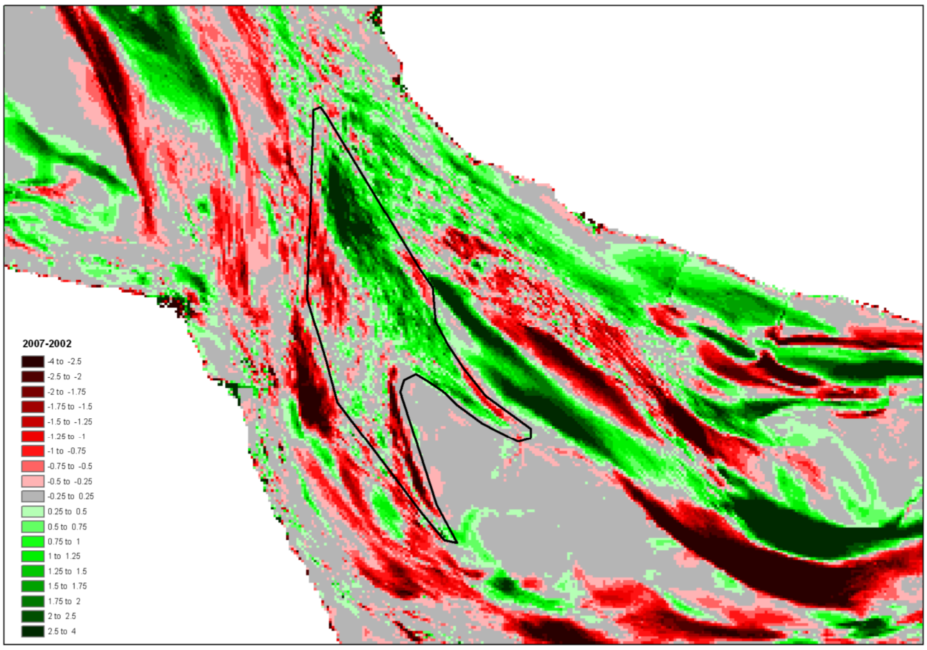


Figure E3: Difference survey between 2002 and 2007

On the basis of the topobathymetric data (source: Zeeland Directorate-General for Public Works and Water Management), year-on-year volume changes were determined for the larger control polygon. The results of this are given in figure E4. The blue line indicates the cumulative volume changes (calculated on the basis of the volume of water under the reference area); the green dots indicate the volume changes per year.

A pretty regular course is observable here between two peaks (2002 and 2004). From 1991 to 2003, a decreasing trend (increase in water volume) can be noted; this gradually reduces. From 1991 to 1996, an average of 650,000 m³ of material disappears from the polygon each year, this reduced to an average of 220,000 m³ per year between 1997 and 2001 (indicated by orange lines). In the subsequent years, growth is visible (reduction of water volume), caused by the relocation test in 2004 and 2006-2007. If, however, the impact of the relocations are considered (volumes from 2005 to 2007 reduced by the disposed volumes – indicated by deviation bar), the trend still appears to be a slight decrease.

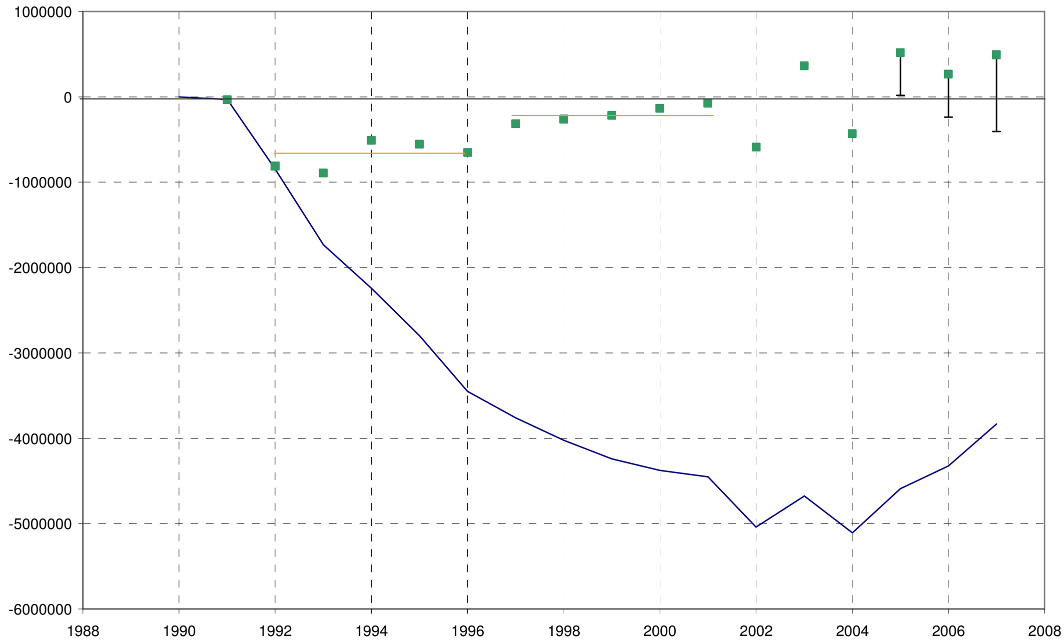


Figure E4: Volume changes from 1991 to 2007 on the basis of data from Zeeland Directorate-General for Public Works and Water Management

On the basis of the Eurosense measurements from 2004 to 2008, the effect of the relocation test and the subsequent erosion has been compared with the general trend that was observed before the relocation tests.

Figure E5 again indicates the cumulative volume changes (calculated on the basis of the water volume under reference level) in blue; the green dots indicate the volume changes year-on-year. The relocation periods are indicated with a yellow background. After each relocation period, the average erosion speed (orange lines) within the larger control polygon was calculated. This provides the following result: about 500,000 m³ per year after the 2004 relocation test, about 860,000 m³ per year after phase A of the 2006 relocation test, and about 720,000 m³ per year after phase B of the 2006 relocation test.

Erosion speeds after the relocation tests are therefore slightly higher than the general trend but remain largely the same size. The erosion from the relocation tests must therefore be framed within a general erosive trend at the location of the seaward tip of the Walsoorden sandbank. A slightly increasing trend was noted at the beginning of 2008. Further monitoring must be carried out in order to ascertain whether the reducing trend has reversed or whether this is a temporary change which is possibly down to seasonal (winter) effects. Comparison with the winters in previous years is not possible as repeated relocation tests were underway at these times.

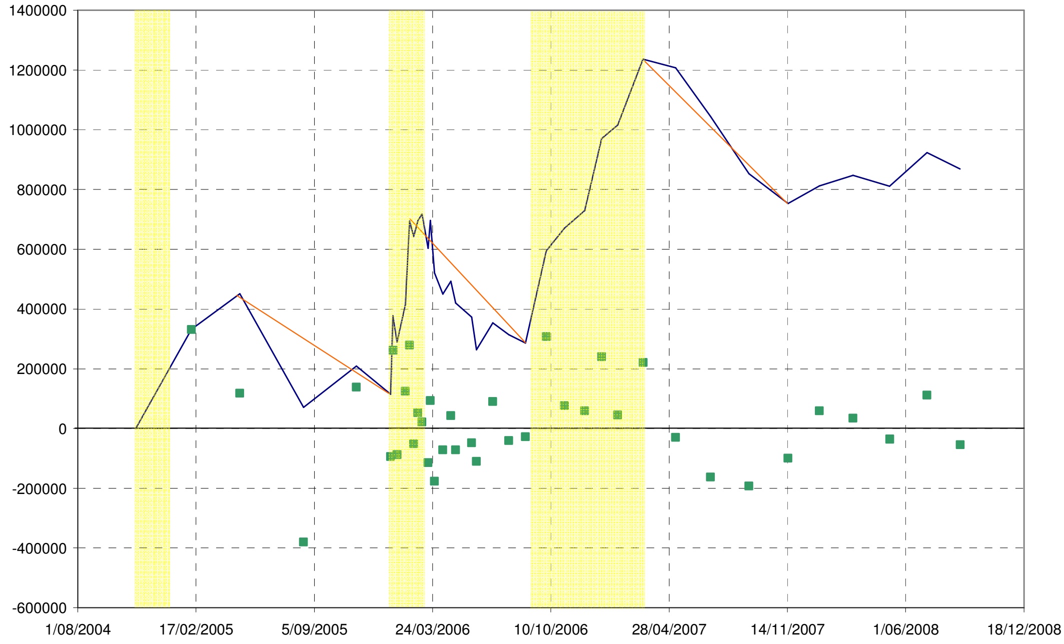


Figure E5: Volume changes from mid 2004 to 2008 on the basis of Eurosense measurements

Waterbouwkundig Laboratorium

Flanders Hydraulics Research

Berchemlei 115
B-2140 Antwerp
Tel. +32 (0)3 224 60 35
Fax +32 (0)3 224 60 36
E-mail: waterbouwkundiglabo@vlaanderen.be
www.watlab.be