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Progress report 2010 on the nourishment on the Galgeplaat

Morphological and ecological developments, 15 months after the construction

CLIMATE PROOF AREAS

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Translated from Dutch by Claire Taylor

1201819-000

Rijkswaterstaat
Ministerie van Verkeer en Waterstaat

CLIMATE PROOF AREAS

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Title

Progress report 2010 on the nourishment on the Galgeplaat

Client	Project	Reference	Pages
Rijkswaterstaat	1201819-000	1201819-000-ZKS-0013	84

Keywords
Galgeplaat, nourishment, Eastern Scheldt

Summary
The Galgeplaat is very susceptible to erosion and as a result its elevation is being continually lowered. After an exploration of possible measures, it was decided to carry out a nourishment on the Galgeplaat. In September 2008 the nourishment was put in place. The goal of the nourishment is to stop the loss of intertidal area (temporarily). The nourishment is being extensively monitored for a period of three years. During this period knowledge is being acquired concerning the development of the nourishment itself and its effects on benthic fauna, birds and the adjacent mussel beds. The main questions here are: 1) Is the nourishment supplying the intertidal flat, 2) How long will the nourished sand remain on the intertidal flat and 3) How long will it take before the benthic fauna has completely recolonised the nourished area.

This progress report is the sequel to the 2009 report. The analysis of the data up to the end of December 2009 shows the following:

- The nourishment has mostly remained in place during the previous 15 months.
- It is mainly the higher areas of the nourishment which are levelling off.
- The nourishment has ensured that the exposure time at the location of the nourishment has increased.
- The surrounding area has not yet been supplied with sand by the nourishment.
- There is clear evidence that the recovery has started. However the benthic fauna has not yet reached the level it was at in 2007.
- There have been no negative effects as a consequence of the dredging and nourishment activities on the growth or development of the mussels on the mussel beds in the area.

References
Previous report (Holzhauer and Van der Werf, 2009)
Task number 1201819-00-ZKS-0005

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final

Contents

1	**Introduction**	**3**
1.1	Background	3
1.2	Objective	4
1.2.1	The possibilities provided by a new surveying method	5
1.3	Relationships with other projects	5
1.4	Layout of the report	5
2	**Monitoring the Galgeplaat**	**6**
2.1	The nourishment	6
2.2	Monitoring the morphology	8
2.3	Monitoring the hydrodynamics	10
2.4	Monitoring the ecology	11
2.5	Other data	15
3	**Result of the analysis**	**16**
3.1	Hydraulic conditions	16
3.1.1	Water levels	16
3.1.2	Wind and waves	17
3.2	Morphological development	19
3.2.1	Bed level at specific locations	19
3.2.2	Bed level along profiles	23
3.2.3	Bed level for the whole area	24
3.2.4	Change in nourishment volume	28
3.2.5	Morphological development of the intertidal flat around the nourishment	28
3.3	Exposed area and duration of exposure	31
3.4	Ecological development	33
3.4.1	Birds	33
3.4.2	Benthic fauna	34
3.4.3	Sediment composition	36
3.4.4	Productivity of the mussel beds	38
4	**ARGUS**	**39**
4.1	The objective of the ARGUS-BIO station on the Galgeplaat	39
4.2	Morphological monitoring with ARGUS	39
4.2.1	Mapping shorelines using video pictures	39
4.2.2	Mapping the Galgeplaat	41
4.2.3	Validation of mapped shorelines for the Galgeplaat	42
4.2.4	First morphological results	46
4.3	Ecological monitoring with the ARGUS-BIO station	47
4.3.1	The ARGUS-BIO camera	47
4.3.2	Images of the biota on the Galgeplaat	48
4.4	Observation of the biogeomorphological processes and interactions	51
4.4.1	Wet areas and sediment composition	51
4.4.2	Bed roughness	52
4.4.3	Diatoms	53
4.5	The future: new measuring methods and apparatus	54

5 Conclusions and recommendations 55
5.1 Conclusions and recommendations for the hydrodynamics and morphodynamics 55
5.2 Conclusions and recommendations for the ecology 55
5.3 Conclusions and recommendations for monitoring 56
5.4 Conclusions and recommendations for the ARGUS-BIO station 57
5.5 Conclusions on the effectiveness of the nourishment 57

6 References 58

Appendices

A Visual inspections 59

B Comparison measurement techniques bed level 75

C Sediment composition 82

1 Introduction

1.1 Background

The Eastern Scheldt is suffering from sand shortage ('sand hunger') as a result of the construction of the Eastern Scheldt storm surge barrier. This sand shortage is a result of the considerable decrease in the tidal fetch and the current speed within the estuary. Consequently, the dynamic balance between the accretion and erosion of intertidal flats, salt marshes and mudflats has been disturbed. The tidal creeks are now too large relative to the reduced tide. The water is flowing more slowly and therefore has insufficient strength to move the sediment onto the intertidal areas. Sand, mainly influenced by the waves, is steadily disappearing from the intertidal areas and as a result the elevation of the intertidal areas is becoming increasingly lower.

The sand shortage is affecting the intertidal flats, mudflats and salt marshes of the Eastern Scheldt. At the moment 50 hectares of mudflats and intertidal flats are disappearing irrevocably under water each year and it is expected that this will increase to 100 hectares per year (Jacobse et al., 2008). For this reason, tens of thousands of birds will not be able to forage for food on the exposed mudflats and intertidal flats. In addition, the intertidal areas form a barrier for waves running up the dike. When these areas disappear, the wave exposure on the dike along the Eastern Scheldt will increase.

To deal with the sand shortage, 400 to 600 million m³ of sand is needed. This amount is 30 to 50 times the annual nourishment volume for the entire Dutch coast. The application of this amount of sand from the North Sea is not achievable either logistically or cost-wise (Van Zanten and Adriaanse, 2008).

The Galgeplaat is one of the intertidal flats in the Eastern Scheldt and is also heavily subject to erosion with its elevation continually decreasing. After an exploration of possible measures, the decision was made to execute a nourishment on the Galgeplaat, which would (temporarily) stop the loss of the intertidal area. The nourishment was carried out in the period of August-September 2008 using sand recovered during dredging activities for the shipping sector in the channel next to the Galgeplaat.

An extensive monitoring program was set up for a period of three years (Ramaekers, 2008). During this period knowledge is being acquired concerning the development of the nourishment and its effects on benthic fauna, birds and the adjacent mussel beds. The main questions here are: 1) Is the nourishment supplying the intertidal flat, 2) How long will the sand remain on the intertidal flat and 3) How long will it take before the benthic fauna has completely recolonised the nourished area.

In 2009 an initial evaluation was made on the development of the nourishment based on the monitoring data from the first three months after it had been constructed (October up to and including December 2008). From this evaluation it was concluded that the nourishment had not changed substantially. The majority of nourished sand was still in its initial position and the benthic fauna was, apart from a few observations, not clearly present (Holzhauer and Van der Werf, 2009).

1.2 Objective

This progress report is the sequel to the 2009 report. There is now data available for the 15-month period after the nourishment was put in place (October 2008 up to and including December 2009). In this progress report the analyses in the first evaluation have been extended using new data. Where possible, forecasts have been adjusted and provisional conclusions have been determined. It is stressed that the emphasis in this progress report is on understanding the separate development of the morphology and ecology. This is to prevent premature conclusions being drawn. Another progress report will follow in 2011 and the final evaluation will take place in 2012. The final evaluation will specifically examine the interactions between the ecological and morphological developments on the Galgeplaat and search for the optimal conditions of such a nourishment. The objective is to ultimately provide answers to the following questions:

1 How is the nourishment moving and spreading?
1.1 Is the nourished material remaining in place?
1.2 Is the shape of the nourishment changing?
1.3 Is the benthic composition changing on or around the nourishment?
1.4 Has there been a change in the current speed?

N.B. Question 1.4 will not be elaborated on in this analysis because there were no new current measurements carried out in the period January-December 2009.

2 What is the effect on the exposed area?
2.1 Is a larger area being exposed than previously?
2.2 Has the time increased that the area is exposed?

3 What is the influence of the nourishment on the wave height?
3.1 Is there a dampening effect?

N.B. Question 3.1 will not be elaborated on in this analysis because there were no new wave measurements carried out on the intertidal flat in the period January-December 2009. However, information is available from the Waverider in the channel next to the Galgeplaat. This data will be included in the report.

4 What is the effect on the foraging behaviour of birds?
4.1 Has the foraging time on the Galgeplaat increased?
4.2 Are there more birds present than before the nourishment?

5 Is the benthic fauna recolonising the intertidal flat?
5.1 Which benthic fauna are recolonising the nourishment location?
5.2 What is the nature and volume of the recolonisation that is taking place?

6 What is the effect of the nourishment on the mussel beds?
6.1 Has the bed level of the existing mussel beds changed?
6.2 What has happened to the production weight of the mussels?
6.3 Have there been increased concentrations of suspended matter in the water?

7 Is the nourishment feasible and sustainable on a larger scale?
7.1 What are the timescales of the ecological and morphological developments?
7.2 Is there an optimal balance between ecology and morphology?
7.3 What would the effect be on a larger scale?

7.4 What will the longer-term effect of the nourishment be and how does this relate to repeated nourishments?

8 Has the nourishment been a success?

1.2.1 The possibilities provided by a new surveying method

In addition to field data, information is also being acquired on the morphological and ecological development of the nourishment on the Galgeplaat using Remote Sensing at the ARGUS-BIO station. The ARGUS-BIO station, which was installed in 2009, is continuously taking photographs of the development of the shoreline (based on which the bed level can be derived) but also of birds, sandworm casts and algae or oyster cover. The ARGUS-BIO station is still in development, not only technically (hardware) but also regarding the processing of the information itself (software). Because of this, it is not yet possible to carry out a full analysis of the developments on the Galgeplaat. Chapter 4 gives a sample of what monitoring with the ARGUS-BIO station could deliver. It is neither the intention nor is it possible to further process the information obtained by the ARGUS-BIO station and/or to enhance the analysis software within this project.

1.3 Relationships with other projects

A number of projects have been carried out in the Eastern Scheldt within the framework of ‘Building with Nature’. Some of these projects, such as ZW 2.21 and ZW 2.32, are specifically related to the Galgeplaat. The emphasis within these projects is on the relationship between the biological and morphological developments.

With regard to the Eastern Scheldt, the ANT (Autonomous Negative Trend) Eastern Scheldt study has started. Within this study further research is being carried out into the possibility of realistic and affordable measures to delay or halt the negative effects of the sand shortage on the habitats of wader populations in the Eastern Scheldt.

1.4 Layout of the report

Chapter 2 describes the survey locations and data for the period from October 2008 to December 2009. The analysis of the monitoring data is given in Chapter 3. The possibilities for the ARGUS-BIO station on the Galgeplaat together with a few first trial runs of the analyses are described in Chapter 4. Chapter 5 contains the conclusions, the discussion and recommendations.

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[1] Monitoring the nourishment on the Galgeplaat with cameras (ARGUS-BIO)

[2] Analysis and modelling of the ecological and morphological developments of the nourishment on the Galgeplaat

2 Monitoring the Galgeplaat

2.1 The nourishment

The nourishment of the Galgeplaat has been carried out using sand from the maintenance dredging work in the Witte Tonnen Vlije and the Brabantsche vaarwater. First a circular embankment was constructed into which 130,000 m³ of sand was pumped in a controlled manner to form a circle approximately 1 m high and with a surface area of 15 hectares.

Figure 2.1 Construction of the nourishment, photographed on 24 September 2008

Three preconditions were established in consultation with the mussel growers from nearby mussel beds, in order to prevent any possible negative effects for the mussel sector during the execution of the nourishment.

1. No increase in the turbidity of the water during the execution of the nourishment
2. No uncontrolled discharge of water with sediment
3. Sand only to be pumped during the tidal window of -60 up to +40 cm NAP

A monitoring programme was set up in order to be able to follow the development of the nourishment, in which the following parameters were measured:

<u>During the construction</u>

- Bed level in the mussel beds (using a multi-beam echo-sounder)
- Suspended matter around the intertidal flat
- Production weight of the mussels in the adjacent mussel beds.

<u>Periodically</u>

- Current speed on the intertidal flat and in the channel around the intertidal flat
- Waves on the intertidal flat (using a pressure meter)

<u>Continuously</u>

- Sedimentation and erosion of material on the intertidal flat and the nourishment location
- Bed level of the intertidal flat and the nourishment location (using a single beam echo-sounder along transects with a distance of 25 m and 50 m)
- Bed level profile (using a RTK-DGPS3 along transects with a distance of 25 m)
- Wave height, wave direction and wave period in the channel (using a Waverider)
- Benthic fauna on the intertidal flat and in the nourishment location
- Sediment composition on the intertidal flat and in the nourishment location
- Birds in the nourishment location
- ARGUS-BIO station. Continuous images of the water level, the presence of benthic fauna, macroalgae and birds.

The surveyed parameters are described in more detail in the following paragraphs.

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[3] *RTK stands for Real Time Kinematic and is a special form of DGPS. DGPS stands for Differential Global Positioning System that determines vertical and horizontal positioning with a high accuracy.*

2.2 Monitoring the morphology

The morphological developments are being measured based on visual monitoring, sedimentation-erosion measurements in various places, measurements of the bed level for the whole nourishment area and additional bed level measurements along 3 different transects. Combining the different types of measurement gives a sufficiently accurate and comprehensive sedimentation-erosion pattern.

Table 2.1 Measuring frequency of the morphological developments

Parameter	T0	2007	YAER 1	2008				2009				
		T0		T1	T2	T3	T4	T5	T6	T7		
Visual monitoring					29 Oct	26 Nov		14 Jan	11 Feb	11 Mar	1 Apr	13 May
Sedimentation-erosion plot				3 Oct	29 Oct	26 Nov		14 Jan	11 Feb	11 Mar *	1 Apr	13 May
Bed level (Single beam 25m)		6-8 May		17, 20 Oct	29, 31 Oct	11,12,19 Nov	12-17 Dec	12, 13 Jan	9 Feb	11-17 Mar		
Bed level (RTK-DGPS)										13 Mar		
Bed level (Single beam 50m)		6-8 May					12-17 Dec					
Bed level profiles (RTK-DGPS)				21 Oct	30 Oct	19 Nov				13 Mar		
ARGUS-BIO										15 Mar - May		

*NB From March 2009 3 extra Sedimentation erosion plots were measured.

Parameter	2009				JAAR 2	2009				2010	
	T8	T9		T10					T11		
Visual monitoring	10 Jun	22 Jul	12 Aug	17 Sept			21 Oct	18 Nov	16 Dec	20 Jan	17 Feb
Sedimentation-erosion plot	10 Jun	22 Jul	12 Aug	17 Sept		6 Oct	21 Oct	18 Nov	16 Dec	20 Jan	17 Feb
Bed level (Single beam 25m)		22 Jul		21,22 Sept							
Bed level (RTK-DGPS)	24 Jun								22 Dec		
Bed level (Single beam 50m)				21,22 Sept							
Bed level profiles (RTK-DGPS)	24 Jun					6 Oct			22 Dec		
ARGUS_BIO	Jun - Sept					Oct - Dec				Jan –Fe	

Visual monitoring

The visual monitoring takes place using photographs taken at specific locations marked with bamboo sticks (see Figure 2.2). More information on these measurements can be found in the visual inspection reports which are included in Appendix A.

Bed level: Profiles

Along three transects the profile the bed level is measured once every three months using an RTK-DGPS system (see Figure 2.2) with an accuracy of approximately 0.03 m.

Bed level: Covering the whole area

The bed level is monitored using three different methods, using a single beam echo-sounder along transects with a spatial resolution of 25 m and 50 m and an RTK-DGPS along transects with a spatial resolution of 25 m. The first type of survey covers only the nourishment itself (see Figure 2.2) and is carried out every 1 to 3 months. The second type of survey is carried out approximately 2 to 3 times per year and covers the nourishment area as well as the intertidal flat perimeters. RWS-Zeeland converted both single beam measurements into grid data with a cell size of 2.5 m and 5.0 m respectively.

The synoptic picture which is the result of the single beam measurement is not sufficiently accurate to show small variations in the bed level (accuracy is in the order of 0.1 m). In

March, July and December 2009 the single beam measurements of the nourished area (first type of survey) were replaced by a comprehensive RTK-DGPS survey along transects with a resolution of 25 m. However, for the larger area which extends over the intertidal flat perimeters, the single beam measurements are still being used.

In addition to these bed level measurements the bed level can also be determined indirectly using images from the ARGUS camera. Photographs of the shoreline are taken every five minutes during ebb tide and are subsequently converted into a map of the bed level. This state-of-the-art Remote Sensing technique is described in more detail in Section 4.2.

Bed level: Sedimentation-erosion
In order to gather the sedimentation/erosion rate at a specific location the local bed level is measured with respect to a fixed reference level. This gives accurate information (in the order of 0.1 m) about the bed level changes, but only in a few limited places. Sedimentation-erosion measurements are carried out at 14 locations (see Figure 2.2) along three transects in the nourishment area (see Figure 2.2). In this way, the spatial development is ascertained. Eleven locations have been measured each month since October 2008. In March 2009 three locations on the higher part of the nourishment (SET 101, 102 and 103) were added.

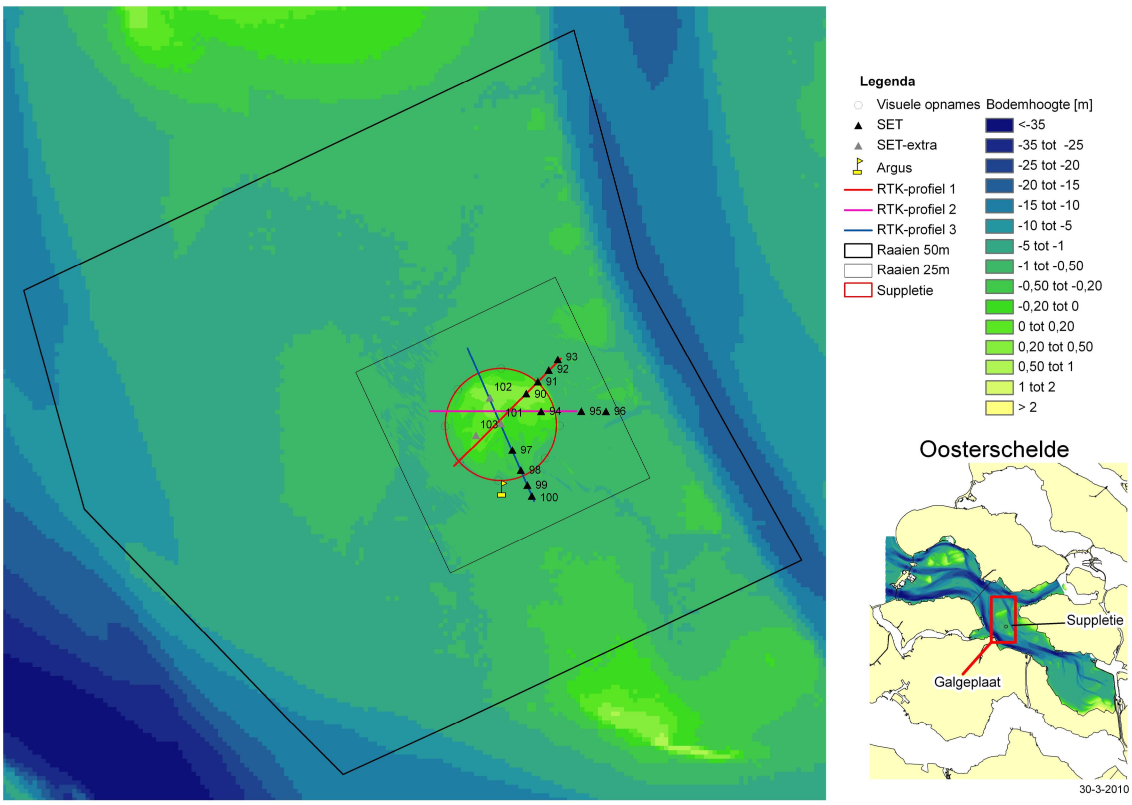


Figure 2.2 Overview of locations for monitoring the morphological developments

2.3 Monitoring the hydrodynamics

Waves and currents largely determine the hydrodynamics around the Galgeplaat. The expectation was that the nourishment would be able to influence the currents and waves around the Galgeplaat. Current speeds on the intertidal flat and in the channel together with the waves on the intertidal flat and around the intertidal flat were measured before as well as shortly after the construction of the nourishment, for a period of a month (see Figure 2.3) These hydrodynamic measurements have not yet been repeated since the first survey campaigns in May-June 2008 and October-November 2008. Analysis of these measurements has not shown any definite changes in the currents over the intertidal flat nor any wave-dampening effect as a consequence of the nourishment (Mol and Aardoom, 2008; Holzhauer and Van der Werf, 2009). This report will not repeat the analysis of the current and wave data. In 2010-2011 it is intended that the current and wave measurements will be carried out again. The subsequent report will include the analysis of this data. In addition to the ADCPs and pressure meters, a Waverider was installed in May 2008 in order to measure the dominant wave climate. This is still in place and will be included in the analysis in this report.

Table 2.2 Measuring frequency of the hydrodynamic parameters

Parameter	T0	2008	JAAR 1	2008	2009	JAAR 2	2009	2010
		T0		T1				
ADCP on the intertidal flat (STR 1-4)		9 May – 19 Jun		3-29 Oct				
ADCP in the channel (STR 5-7)				30 Oct – 28 Nov				
Pressure meter (DD1, DD2)		10 May - 19 Jun		4 – 29 Oct				
Waverider		May - Sept		Oct - Dec	Jan - Sep		Oct - Dec	Jan - Mar

Waverider

The Waverider, a directional wave buoy, is positioned 200 m southwest of the Galgeplaat in the Engelsche Vaarwater (see Figure 2.3). It measures vertical and horizontal accelerations every half hour, from which the wave height, wave period, and wave direction etc. are derived.

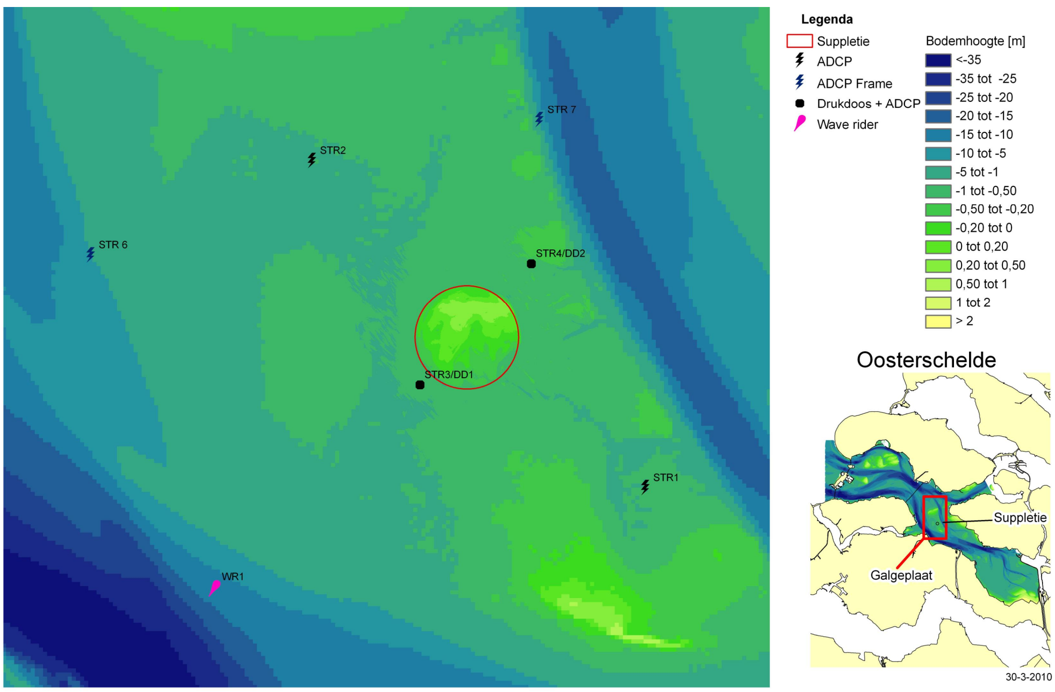


Figure 2.3 Overview of locations for monitoring the hydrodynamic developments

2.4 Monitoring the ecology

The ecological developments are examined on the basis of benthic samples, bird counts and the development of the mussels in the nearby mussel beds. The sediment composition, as well as the benthic fauna, are determined from the benthic sampling. The sediment composition is an important parameter for the settlement of benthic fauna and other organisms.

Table 2.3 Measuring frequency parameters for the ecology

Parameter		2007		2008		2009
		T0		T1		T2
Benthic fauna	T0	15,17 Oct	JAAR 1	15,20 Oct	JAAR 2	5 Oct
Sediment composition		15,17 Oct		15,20 Oct		5 Oct
Birds		14,15 Oct				8,9 Oct
ARGUS-BIO						31 Jul-Dec
Mussel bed productivity				16 Jun – 13 Oct		16 Feb – 12 Oct

Benthic samples

The sediment composition, the benthic fauna density and biomass are determined from the benthic samples taken in 2007, 2008 and 2009 and analysed by NIOO-CEME (Sistermans et al., 2008; Escaravage et al., 2009; Sistermans et al., 2009). In October 2007 (before the nourishment was put in place) the first set of benthic samples (T0) were taken in 16 locations. After the nourishment a second (T1) and third set (T2) of benthic samples were taken, in 2008 and 2009 respectively. Based on the results from the initial (T0) study in 2007 the sampling locations were adjusted in 2008 and 2009 in order to allow for a division into ecotopes (based on advice from Dick de Jong). The division of the various locations into ecotopes is given in the table and figure below.

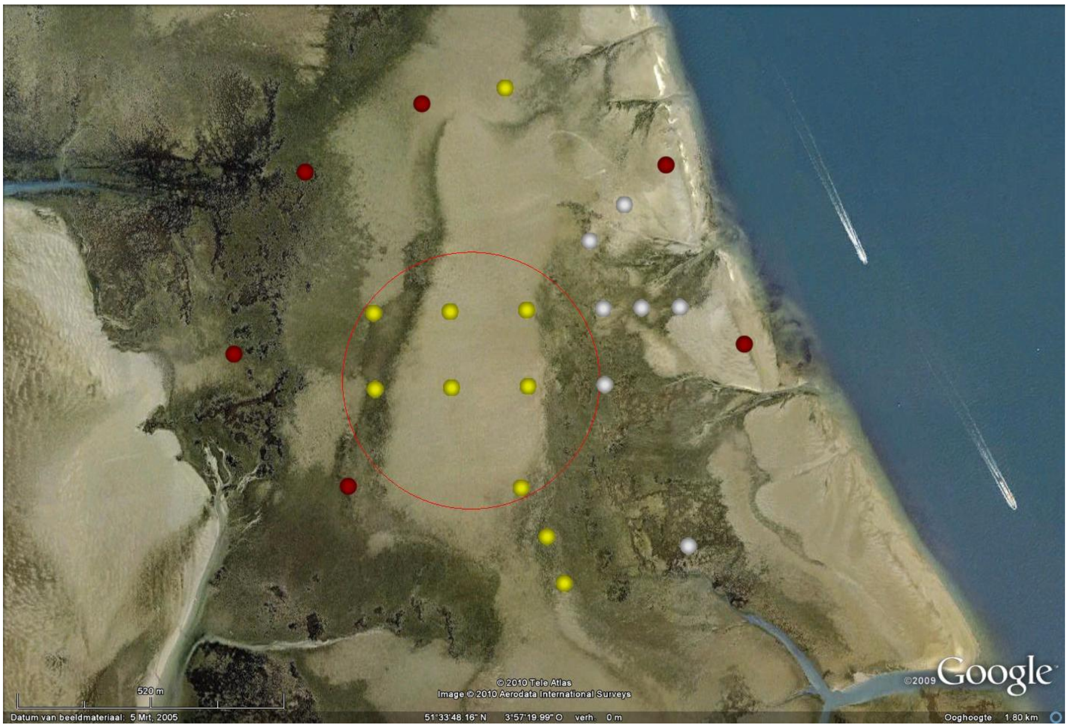


Figure 2.4 Ecotopes on the Galgeplaat. Yellow = open intertidal flat, red = Macroalgae-rich with worms, white = Macroalgae-rich with cockles (based on consultation with Dick de Jong).

Table 2.4   Division of the locations into ecotopes

Ecotope	Location number
Open intertidal flat	*1*, **2**, **3**, *5*, **6**, **7**, **9**, **13**, 21, 22
Macroalgae-rich areas with mainly worms	**10**, *11*, **14**, *15*, *16*, 17
Macroalgae-rich areas with cockles	**4**, *8*, *12*, 18, 19, 20, 23

NB Italic text = only measured in 2007, bold text = measured in 2007-2009, normal text = measured in 2008 and 2009.

The reason for moving the sampling locations was to focus on which changes in benthic fauna have appeared on a global intertidal flat level rather than on a location-specific level. The movement of the sampling locations means that nine sampling locations are the same as the original locations in 2007 and seven locations have been moved (see Figure 2.5 for the siting of the old and new benthic sampling locations).

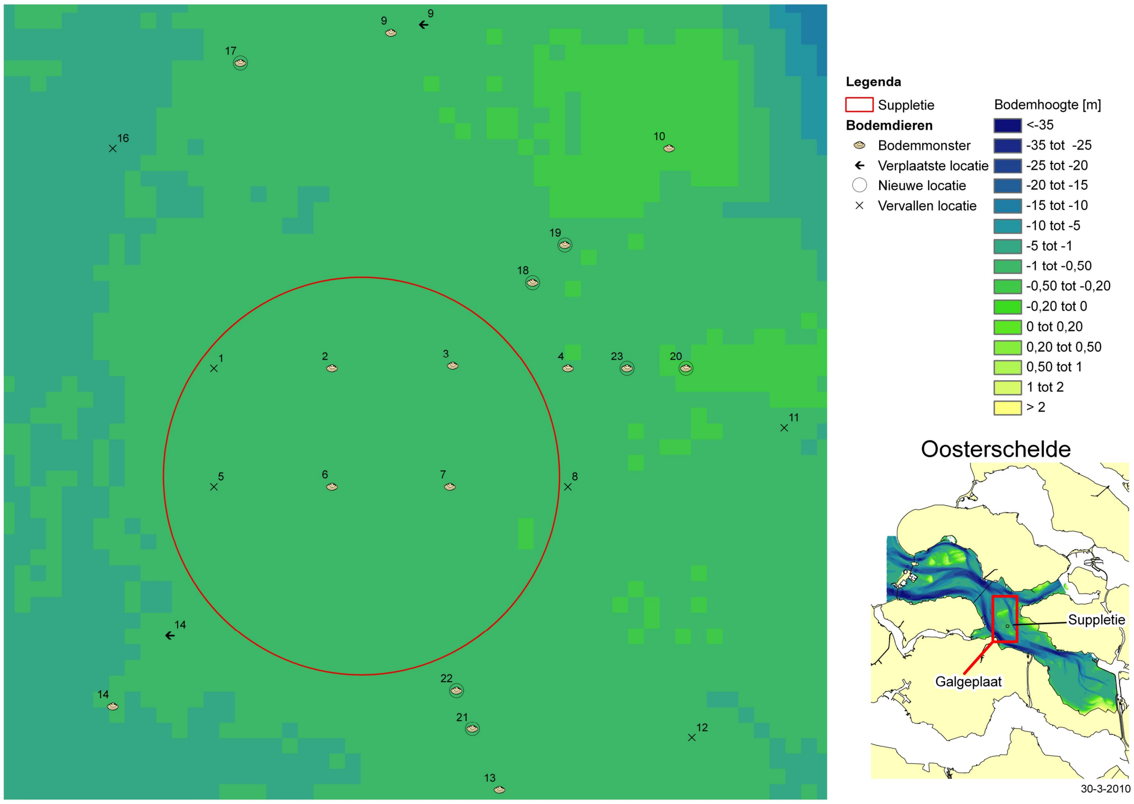


Figure 2.5   Overview of the benthic sampling locations, including the relocations.

<u>Benthic fauna samples</u>

At each sampling location, 6 cores of 8 cm diameter (0.005 m^2) are taken within a radius of 5 meters of the defined sampling point. The core is pushed approximately 30 cm into the sediment and then the contents of each core is sieved through a 1 mm sieve. Afterwards the residue is put into a sample pot and brought to the laboratory for analysis. In the laboratory the samples are sieved again (0.5 mm) and the species are determined under the microscope and weighed. With the help of fixed conversion factors the ash-free dry weight is calculated on the basis of the wet weight.

For shellfish the ash-free dry weight is calculated using a length/weight regression from the same year and season. Shell fragments where no length can be determined are weighed wet and then the ash-free dry weight is calculated using a conversion of the wet weight.

Sediment samples
At each sampling location three small tubes of approximately 1 cm diameter are inserted into the sediment to an average depth of 5 cm around the defined sampling location and then mixed into 1 combined sample. Afterwards the samples are frozen, freeze-dried and sieved. A Malvern particle size analyser is used to measure the distribution of grain sizes in the sediment. Important parameters are the percentage of sand (grain diameter larger than 0.063 mm), the median grain size (D50) and the grain size whereby 10% and 90% of the mixture is smaller (D10 and D90).

Bird surveys
Two bird surveys took place in October 2007 (T0) and 2009. Both surveys were carried out by Habitat Advies (Geene and Gloedbloed, 2007; 2009). In both surveys the wading birds were counted from a small mussel trawler during the ebb tide at an interval of 15 minutes. In 2007 eight large sections (150 x 150 m) were used. In 2009 nine smaller sections were defined in different locations (Figure 2.6). During the survey a distinction was made between foraging and non-foraging birds. The results were converted into the number of foraging minutes per species of bird.

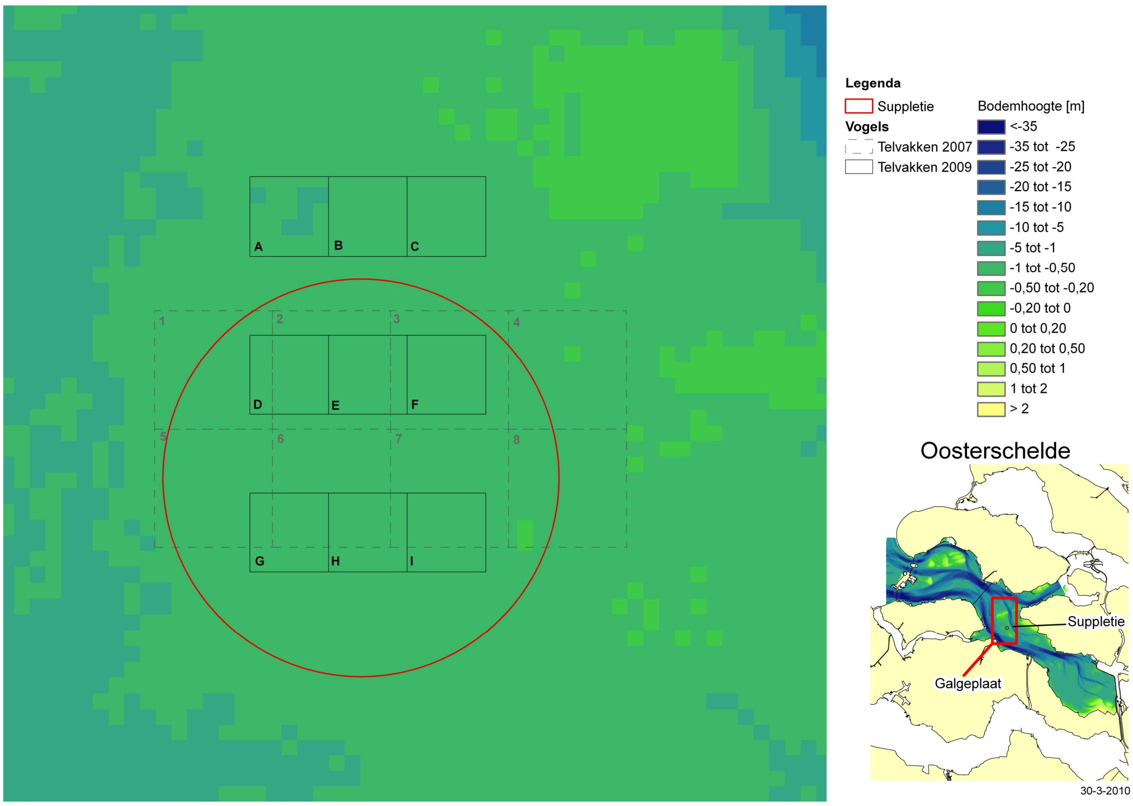


Figure 2.6 Overview of bird surveying locations

As well as a direct count of birds, birds were also indirectly counted using the ARGUS-BIO station. From the ARGUS-BIO station photographs of birds are taken with a movable camera. The pictures can be converted afterwards into bird maps. As well as birds, photographs can be taken of algae, oysters and sandworm casts etc. The possibilities for this state-of-the-art Remote Sensing technique are described in more detail in Section 4.3.

Productivity in the mussel beds

De Mesel (2009) investigated in 2008 the productivity of the adjacent mussel beds. During this study five mussel beds around the Galgeplaat were sampled 8 times with a 1-meter trawl. Three of these plots were situated on the west side of the Galgeplaat (P1 to P3) and two plots were situated on the east side of the Galgeplaat (P4 and P5). In 2009, the three plots on the west of the Galgeplaat (P1 to P3) were sampled 10 more times (see Figure 2.7). All the mussels were analysed for growth. The fresh weight and ash-free dry weight of the complete sample was also determined.

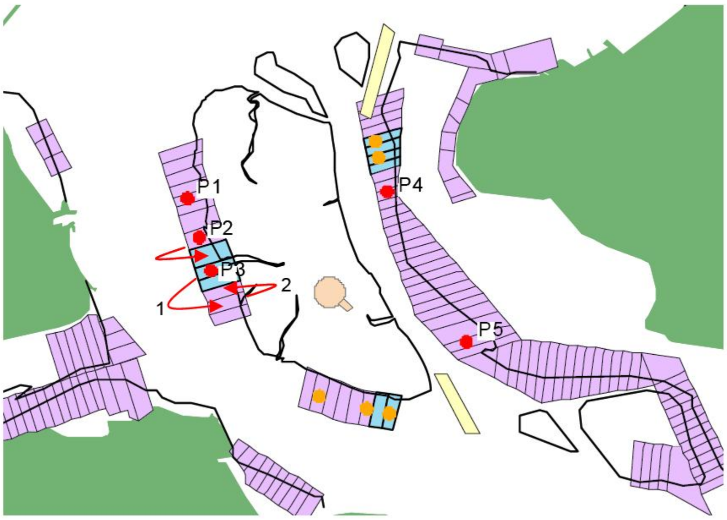


Figure 2.7 The position of the sampled mussel beds around the Galgeplaat. Purple cells = control beds. Blue cells = beds possibly under influence of dredging (yellow areas) and/or of nourishing (pink areas). Red dots = sampled beds. Orange dots = beds that could not be sampled because no mussels had been sown (De Mesel et al., 2009).

As well as the sampling of the mussel beds, seven cages with semi-adult mussels were placed in order to follow the growth of the mussels independently of the activities of the mussel growers (see Figure 2.8). In 2008 three cages were placed on the west side (K1 to K3, of which K2 was washed away and later replaced), two cages were placed on the south side (K4 and K5) and two cages were placed on the east side (K6 and K7, of which K6 was washed away and K7 could not be sampled). In 2009, new cages were placed in K1 to K3 which were then sampled nine times. The analysis of the mussels in the cages was the same as for the mussels from the mussel beds.

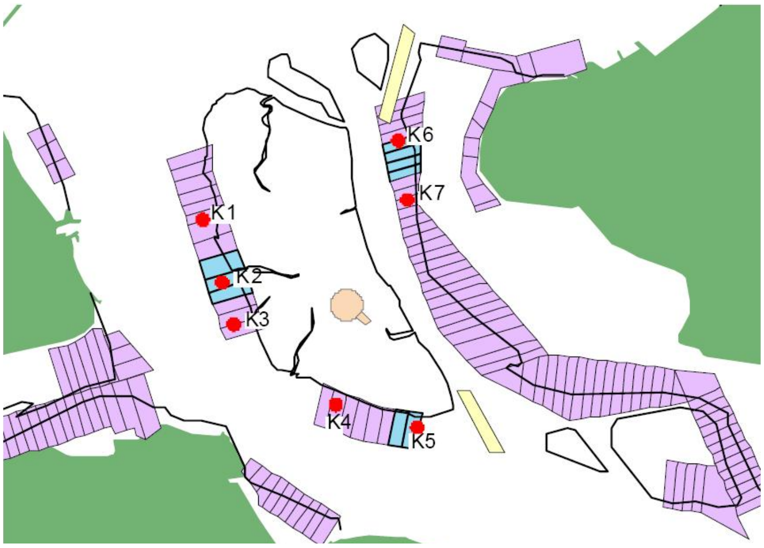


Figure 2.8 The position of the mussel cages. Purple cells = control beds. Blue cells = beds possibly under influence of dredging (yellow areas) and/or of nourishing (pink areas). Red dots = location of mussel cages (De Mesel et al., 2009).

2.5 Other data

As well as the direct measurements on the Galgeplaat, additional information about the tide, wind and waves was used from measuring stations relatively close to the Galgeplaat. This data includes the wind speed, wind direction and water level measured at Stavenisse (STAV); the wind speed, wind direction, water level, wave height and wave period measured at Marollegat (MRG); and the wave height and wave period measured at Keeten (KEET). Figure 2.9 shows the location of these measuring stations.

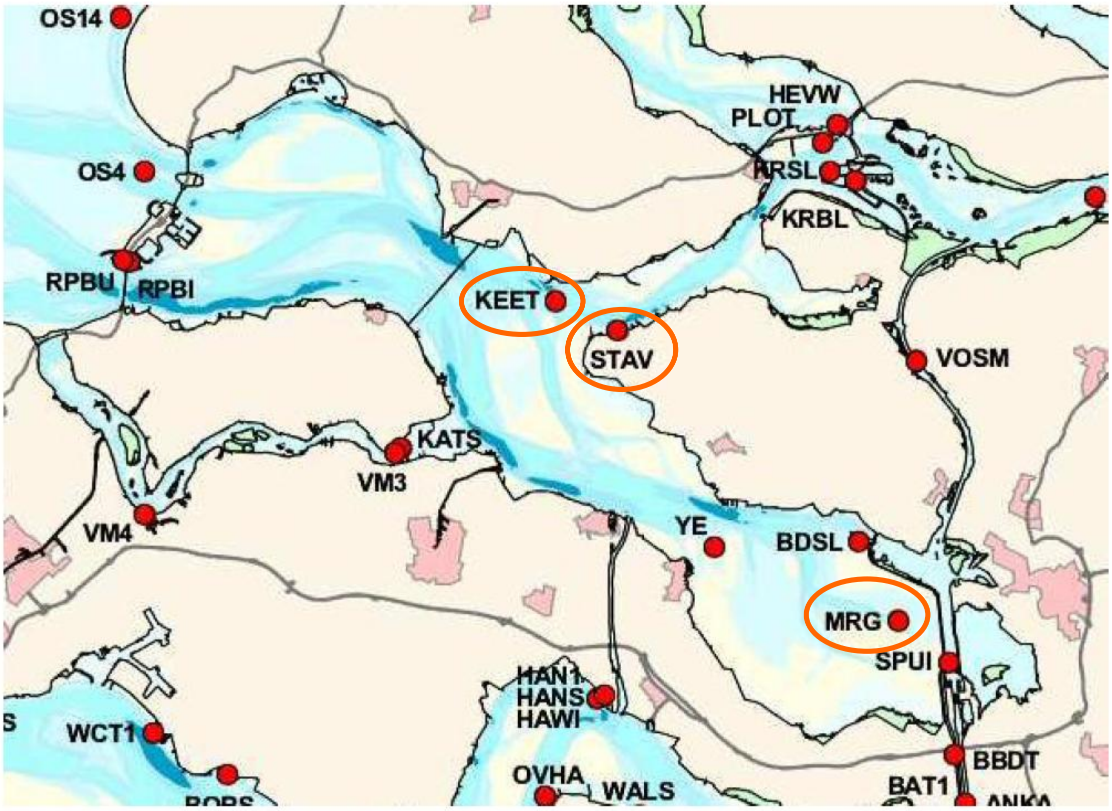


Figure 2.9 Overview of the measuring stations in the Eastern Scheldt. The stations Keeten (KEET), Stavenisse (STAV) and Marollegat (MRG) are circled. (Source: http:/www.hymcz.nl)

The wind data from the Marollegat is suitable because this station is surrounded by 'free water' on the north as well as on the west, as is the Galgeplaat. Comparison of the data gives information on the spatial variation in wind speed, wind direction and water level as well as the wave height and wave period. The data is calibrated by the Hydro Meteo Centrum Zeeland (HMCZ) and stored as 10-minute (wind and tide) and 30-minute (waves) averaged values.

3 Result of the analysis

3.1 Hydraulic conditions

3.1.1 Water levels

The water level in the Eastern Scheldt is not always the same throughout the tidal period. This is primarily due to the shape of the Eastern Scheldt. In 2008 and 2009 the average high tide at Marollegat was +1.8 m NAP and the average low tide was -1.6 m NAP. At Stavenisse, the tidal difference was smaller, with an average high tide of +1.6 m NAP and an average low tide of -1.3 m NAP. These average values are periodically exceeded, for example during spring tide the high tide can reach approximately +1.9 m NAP and the low tide can reach an average of -1.7 m NAP (Figure 3.1).

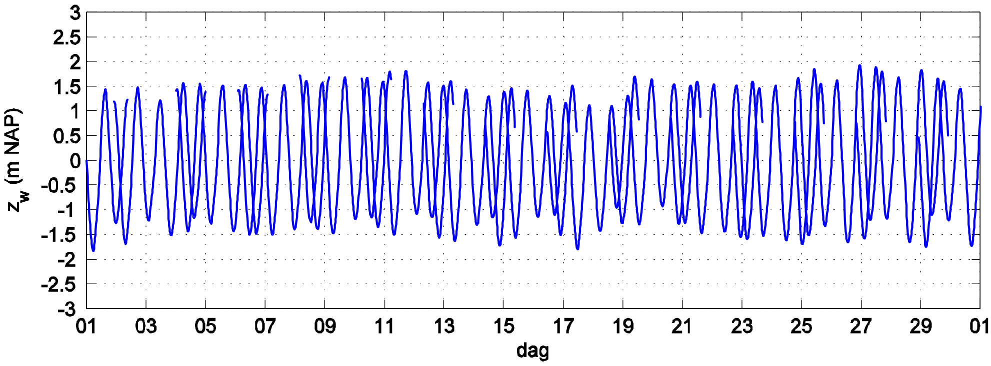


Figure 3.1 Water level at the tidal station Stavenisse in June 2009.

The tide station at Stavenisse was used to calculate the duration of time that the flats are exposed because these water levels are more comparable with the local water levels on the Galgeplaat. The following figure shows the period of undershoot for the measured water levels in Stavenisse (Figure 3.2).

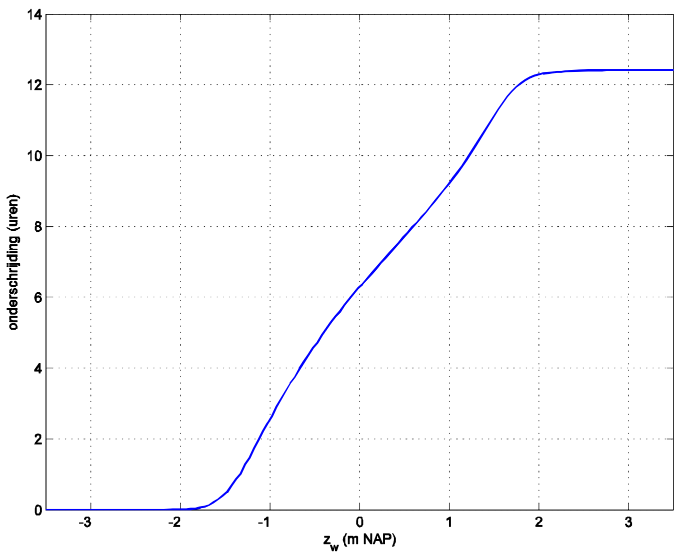


Figure 3.2 Period of undershoot in hours per measured water level in Stavenisse in the years 2008 and 2009.

3.1.2 Wind and waves

In 2008, the maximum wind speed measured at Marollegat and Stavenisse was 23 m/s and the average values were 6.5 m/s and 6.1 m/s respectively. In 2009, the maximum as well as the average wind speeds were slightly lower, measuring 22 m/s and 19 m/s, and 6.1 m/s and 5.8 m/s respectively.

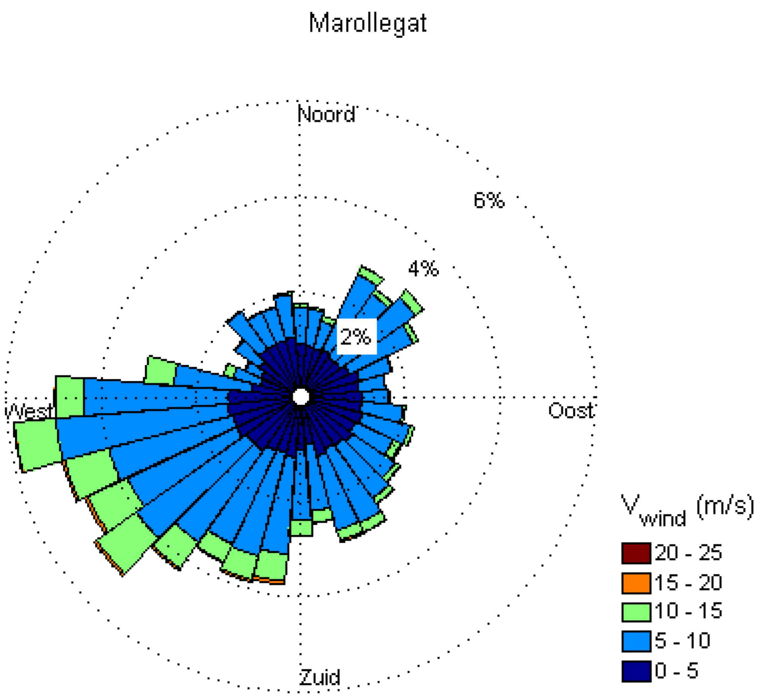
Between the construction of the nourishment in September 2008 and December 2009 there were eight storm events (a wind force of 8 or higher on the Beaufort scale, corresponding to a wind speed of 17 m/s lasting at least half an hour). The following table shows the date and duration of these storms, and the corresponding average wind direction (θ_{wind}) and wind speed (V_{wind}) based on data from Marollegat. The wind direction is defined nautically: 0° corresponds with wind coming from the north and is clockwise. The (average) significant wave height ($H_{1/3}$), significant wave period (T1/3) and the direction of the wave's progress (θ_{wave}, nautically defined) obtained from the Waverider have also been included.

Table 3.1 Storms in 2008 and 2009

		Marollegat		*Wave rider*		
Date	**Duration (hours)**	θ_{wind} (°N)	V_{wind} (m/s)	$H_{1/3}$ (m)	$T_{1/3}$ (s)	θ_{wave} (°N)
01-10-2008	4,5	270	15	0,42	2,7	273
21-11-2008	11	322	14	0,55	3,4	311
19-01-2009	1,2	226	17	0,41	2,6	214
23-01-2009	4,3	289	16	0,66	3,4	296
10-02-2009	0,5	329	17	0,52	3,1	294
03-09-2009	4,2	246	16	0,41	2,7	252
14-11-2009	0,5	216	17	0,21	3,3	221
18-11-2009	1,3	211	17	0,40	2,4	202

The table shows that all the storms correspond with a wind from the northerly and southwesterly direction. The wind and waves originate approximately from the same direction, which indicates that they are generated locally. The waves at the Galgeplaat have an average significant wave height of between 0.2 m and 0.7 m and occur at intervals of between 2.4 s and 3.4 s during these storms. The Galgeplaat was being monitored when a storm took place and it was noted that there was a large amount of aeolian sand transport present (see Appendix A).

Figure 3.3 shows the wind and wave rose based on wind data from the Marollegat and the Waverider data for the year 2009. It can be seen that the dominant wind direction was southwesterly and it should be noted that most of the waves have either a northwesterly or southeasterly orientation. This is probably related to a) wave refraction at the location of the Waverider as a result of currents that are southeasterly-south-southeasterly during high tide and roughly northeasterly during low tide or b) the fact that waves with a northwesterly and/or southeasterly orientation have a larger fetch in the Eastern Scheldt and can therefore progress more. It is recommended that the difference in wind and wave direction is researched further.



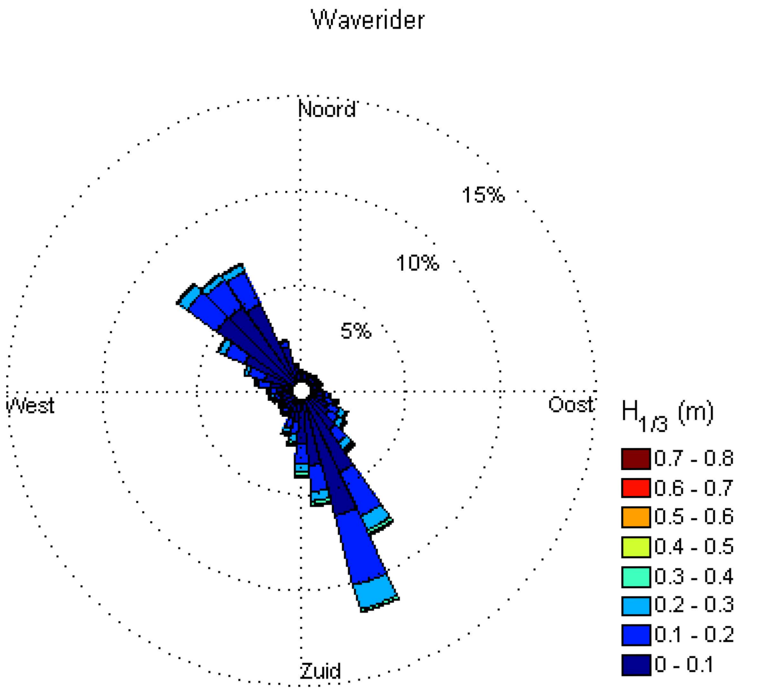


Figure 3.3 Wind rose (above) and wave rose (below) based on wind data at the Marollegat and wave data from the Waverider.

3.2 Morphological development

3.2.1 Bed level at specific locations

Sediment erosion measurements are being carried out at various specific locations on and immediately adjacent to the nourishment. Figures 3.4–3.6 compare these local SET measurements to the bed levels that were determined by linear interpolation of the single beam and/or RTK-DGPS measurements (see Figure 2.2 for the SET locations). The RTK-DGPS profiles have not been included in these figures.

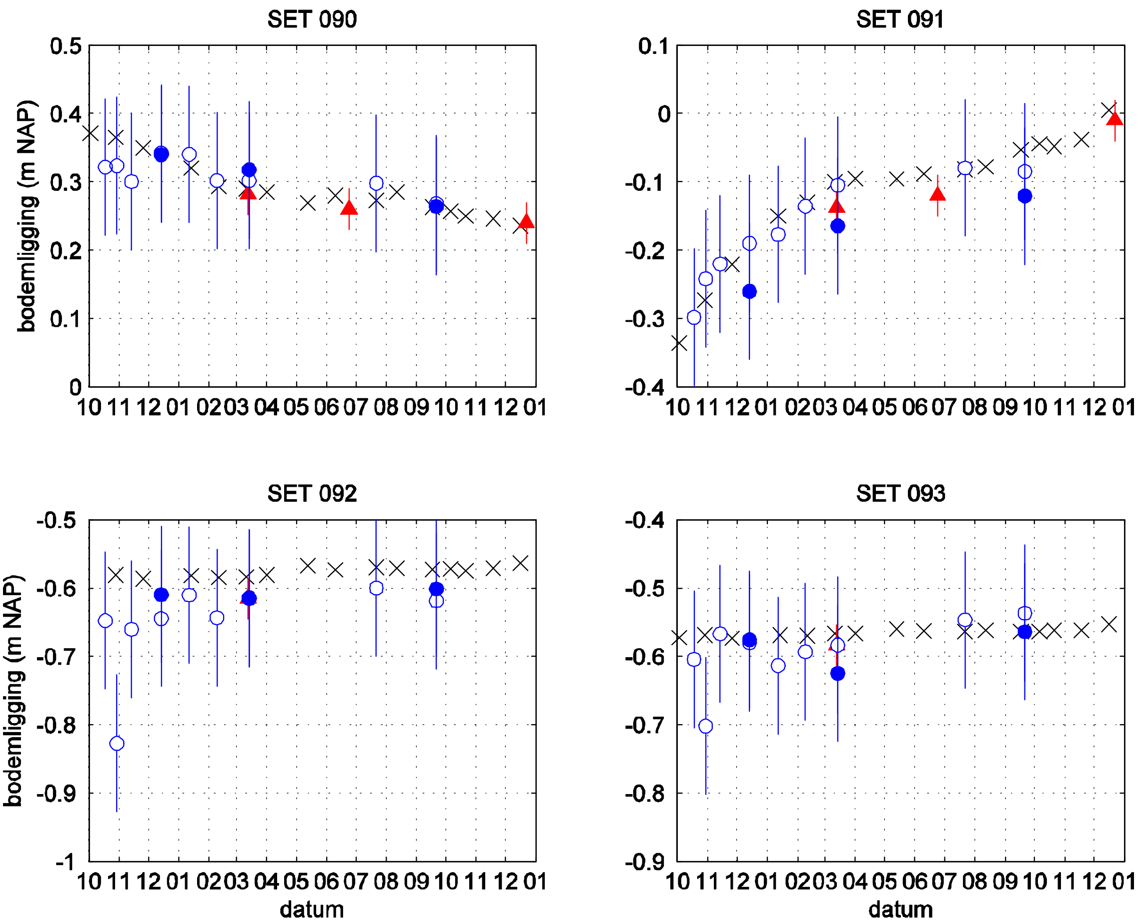


Figure 3.4 Comparison between SET (black crosses), 25 m single beam transects (open blue circles), 50 m single beam transects (solid blue circles) and RTK-DGPS (red triangles) measurements at locations 90-93. The vertical blue and red lines portray the inaccuracy of the single beam (+/- 0.1 m) and RTK-DGPS (+/- 0.3 m) respectively. NB. The scale of the bed level is not the same in each graph.

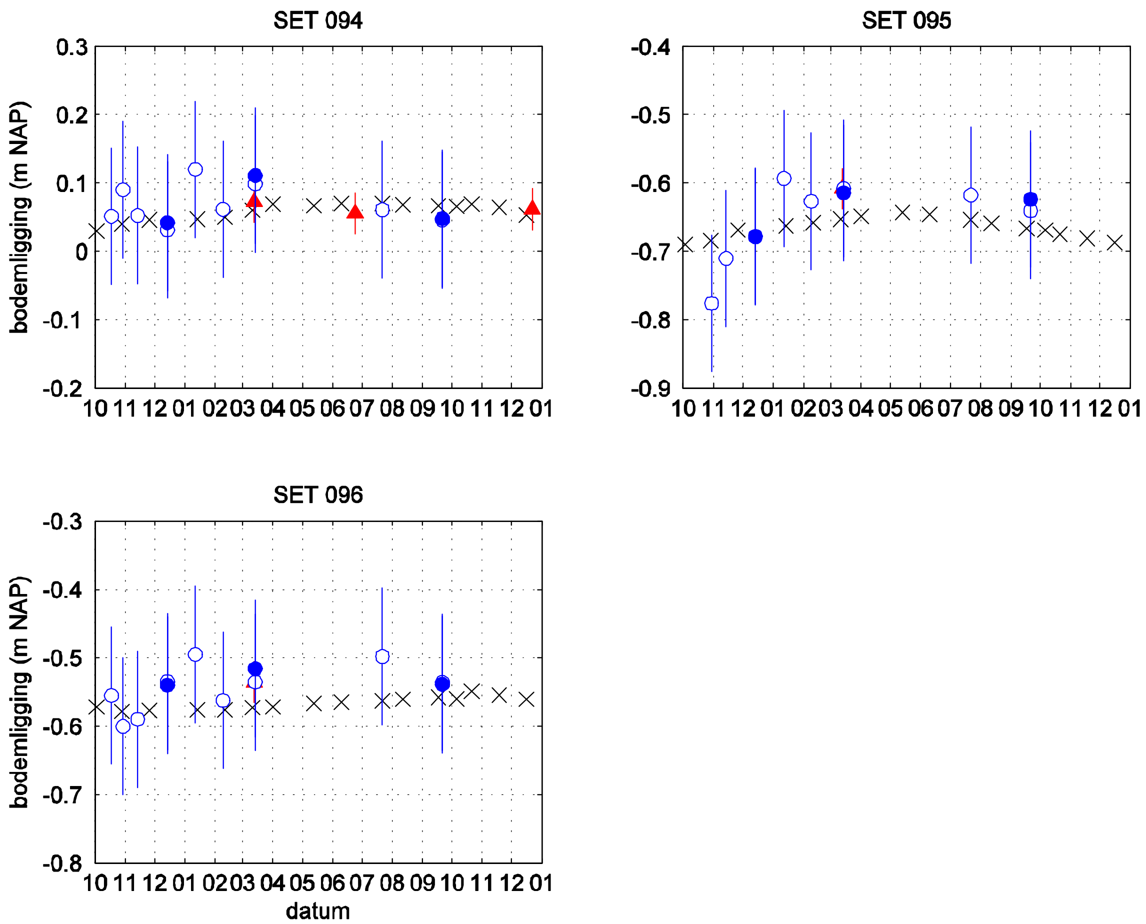
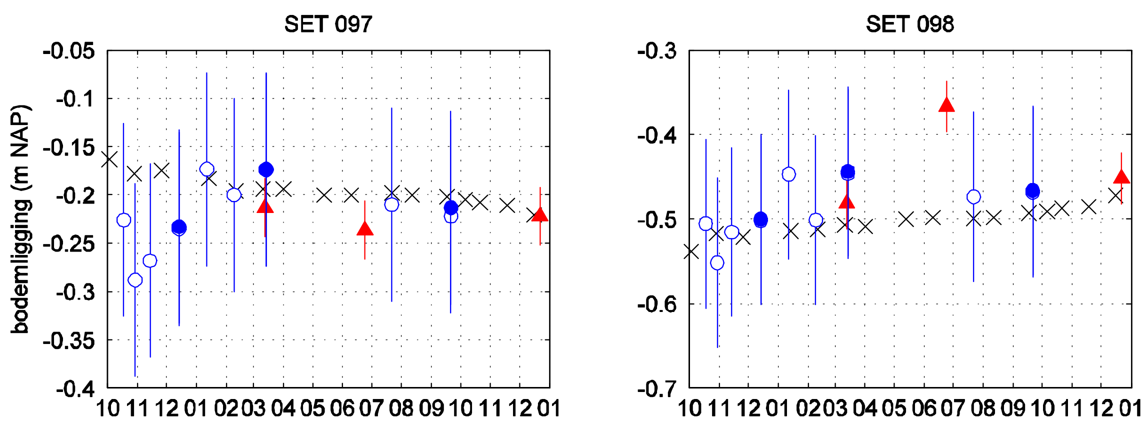


Figure 3.5 Comparison between SET (black crosses), 25 m single beam transects (open blue circles), 50 m single beam transects (solid blue circles) and RTK-DGPS (red triangles) measurements at locations 94- 96. The vertical blue and red lines portray the inaccuracies of the single beam (+/- 0.1 m) and RTK-DGPS (+/-0.03 m), respectively. NB. The scale of the bed level is not the same in each graph.



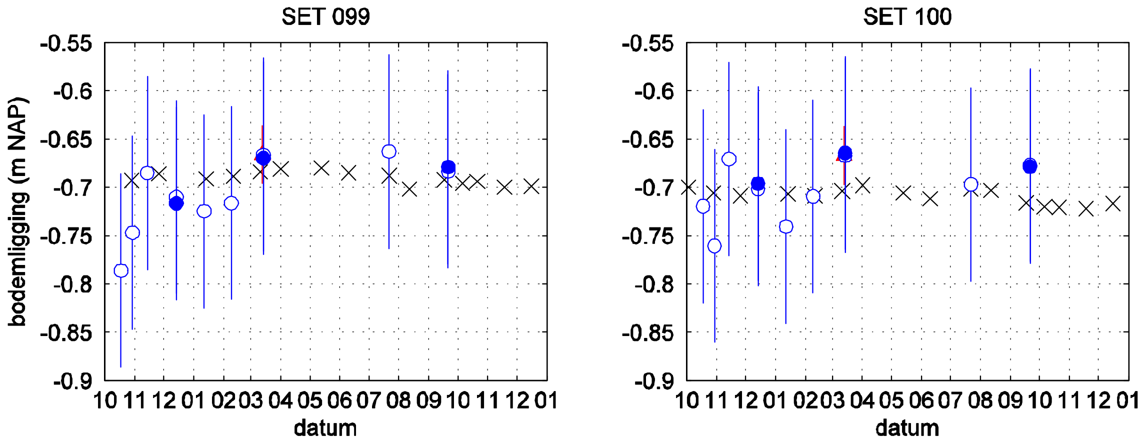


Figure 3.6 Comparisons between SET (black crosses), 25 m single beam transects (open blue circles), 50 m single beam transects (solid blue circles) and RTK-DGPS (red triangles) measurements at locations 97-100. The vertical blue and red lines portray the inaccuracies of the single beam (+/- 0.1 m) and RTK (+/- 0.03 m), respectively. NB. The scale of the bed level is not the same in each graph.

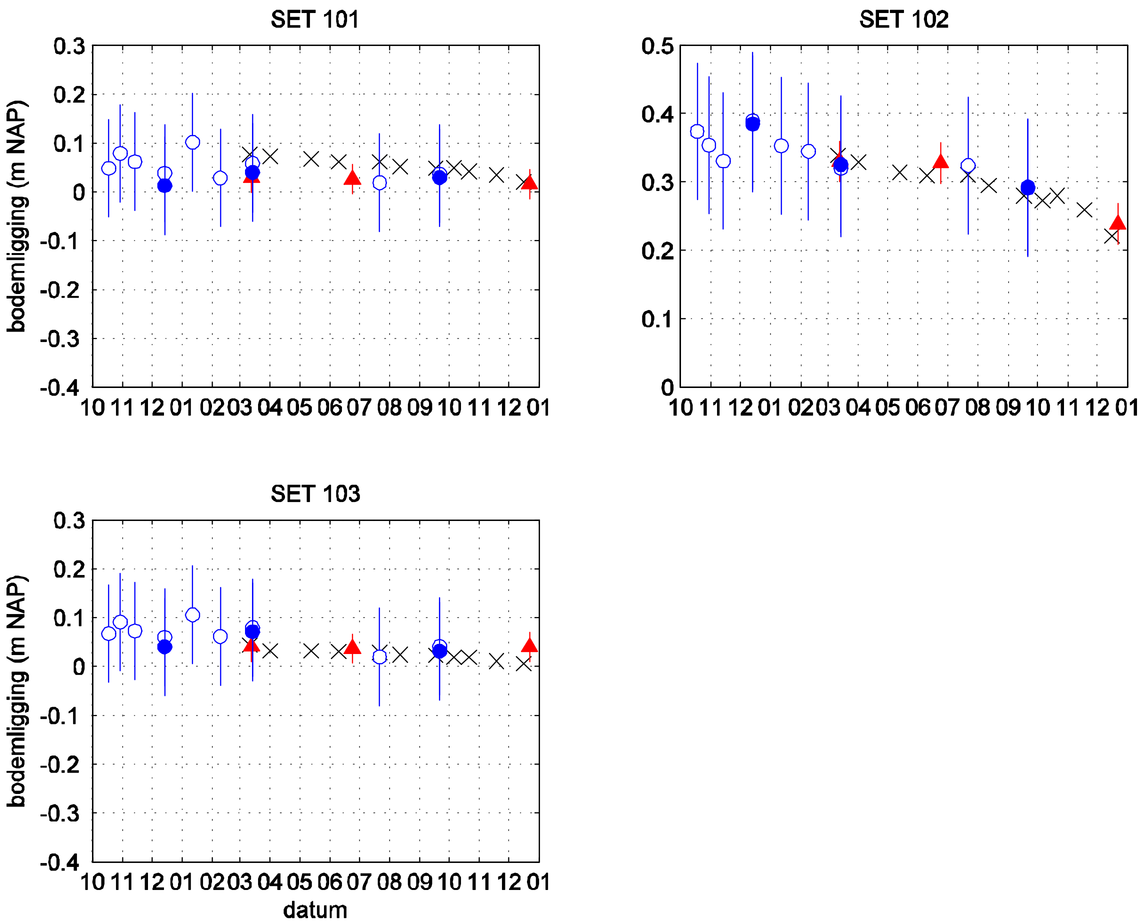


Figure 3.7 Comparisons between SET (black crosses), 25 m single beam transects (open blue circles), 50 m single beam transects (solid blue circles) and RTK-DGPS (red triangles) measurements at locations 101-103. The vertical blue and red lines portray the inaccuracies of the single beam (+/- 0.1 m) and RTK (+/-0.03 m), respectively. NB. The scale of the bed level is not the same in each graph.

Comparison of the measurement methods
These figures show that the bed level derived by the sedimentation-erosion (SET) measurement and the single beam measurement is roughly the same, provided that an inaccuracy margin of +/- 0.1 m is employed for the single beam measurement. This does not apply to the single beam measurements at the SET locations 92 and 93 on 29 October 2008. In this area the single beam measurements systematically underestimate the bed level by 0.2 m (Parée, 2009).

The single beam measurements seem to be less appropriate to follow the small, localised morphological development on the Galgeplaat and the nourishment because of the lower degree of accuracy. However at locations 90, 91 and 102 the SET measurements show a systematic and significant bed level change which is confirmed by the single beam measurements.

The RTK-DGPS measurements are more accurate than the single beam measurements (see also Appendix B) and they correspond closely with the SET measurements. However, in June 2009 at location 98 the RTK-DGPS measurement is approximately 0.12 m too high. Everywhere else, the accuracy of the RTK-DGPS measurements means that the local, annual trends in the bed level are accurate enough to be used.

Results for the SET locations
For the period of analysis (October 2008 up to and including December 2009) the following trends can be observed:

- Strong sedimentation in SET 91 (0.32 m) and SET 98 (0.07 m)
- Light sedimentation in SET 92-94 (0.02-0.03 m)
- Negligible bed level change in SET 95, 96, 99 and 100 (< 0.01 m)
- No perceivable change in SET 99
- Erosion in SET 97, 101 and 103 (0.05-0.06 m)
- Considerable erosion in SET 90 and 102 (0.13-0.14 m)

This implies that erosion occurs on the higher, northern part of the nourishment, whereas the locations along the (eastern) border of the nourishment (SET 91, 94 and 98) experience sedimentation. This suggests that the nourishment is becoming flatter, whereby the sand is moving in a (north) easterly direction. These findings are supported by the visual inspections (see Appendix A).

The SET measurements show the possibility of a seasonal effect. In the SET locations 90 and 91 most erosion and sedimentation takes place in the autumn and in winter (September up to and including March) when there are generally higher wind speeds than in the spring and summer (April up to and including August). This is also visible, albeit on a smaller scale, in different locations (especially SET 97 and 98), supported by the visual inspection in June 2009 (see Appendix A).

The biggest changes are on the northeast border of the nourishment (locations 90 and 91) and on the higher part of the nourishment (location 102). The influence of storms is also visible here. For example, after the storms on 21 November 2008, 19 and 23 January, 10 February and 3 September 2009, the erosion in SET 90 was relatively large. The storms in September and November 2009 resulted in relatively strong sedimentation and erosion at locations 91 and 102. Further research is needed to determine the relationship between bed level changes, the wind and tidal conditions. A start has already been made with this by Das (2010) (in preparation) using a Delft3D model.

3.2.2 Bed level along profiles

Figure 3.8 shows the development of the bed level along three profiles that were measured using the RTK-DGPS. The morphological development is fairly clear. The higher parts have eroded (0.1 m – 0.2 m in the analysis period). The steep edge of the nourishment is smoothed off and shows a small shift. In Profile 1 this shift is in a northeasterly direction, in Profile 2 the shift is eastwards and for Profile 3 the shift is northwesterly. In the 15 months being analysed, this shift is in the order of 10-20 m and most visible on the northeasterly edge (Profile 1).

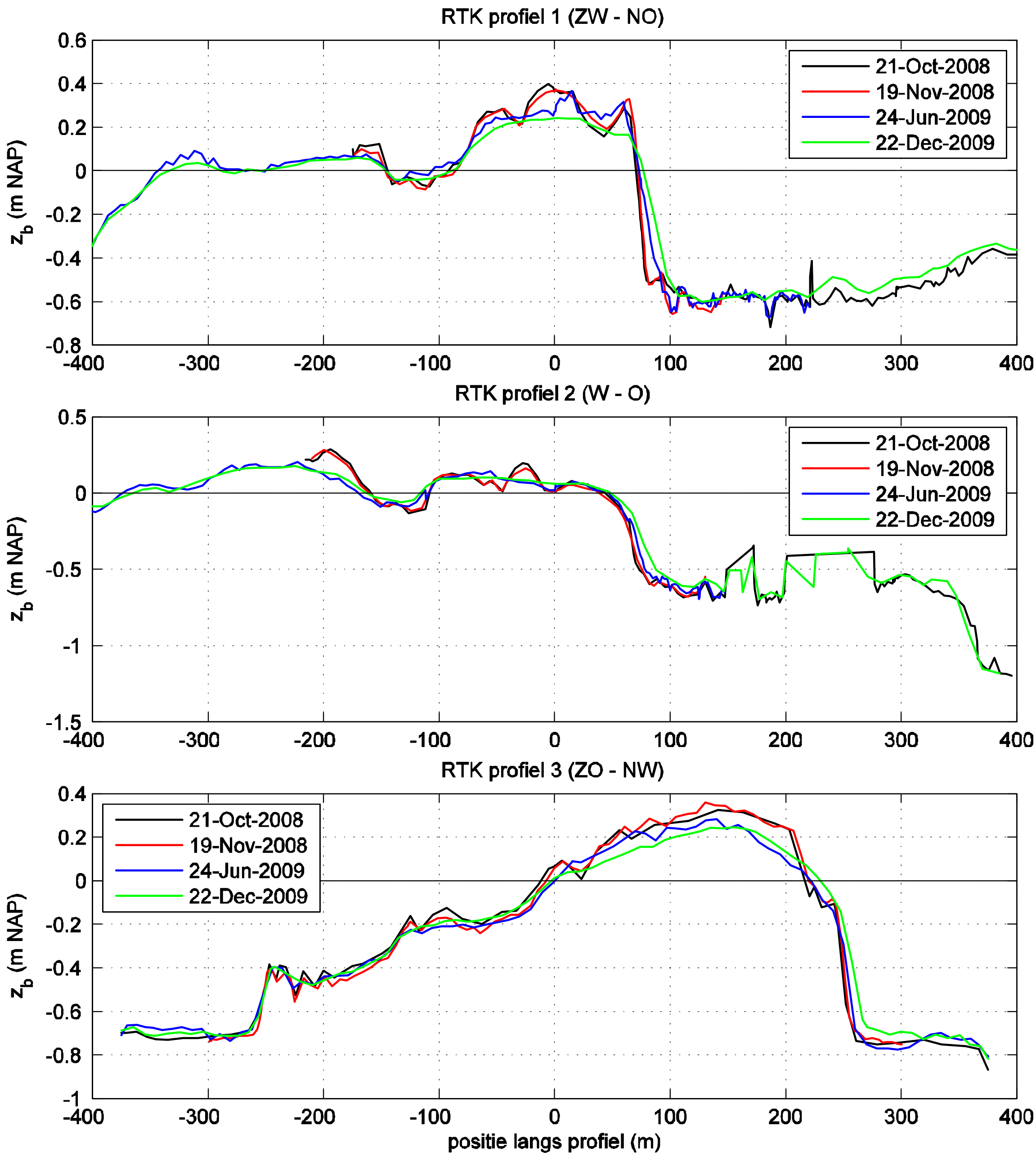


Figure 3.8 Morphological development along the profiles

3.2.3 Bed level for the whole area

Using single beam measurements and the RTK-DGPS measurements at the 25m transects, an image of the bed level is produced for the whole area. This image is derived by interpolating the single beam and the RTK-DGPS measurements onto a grid with a cell size of 2.5 m and 5.0 m for the 25 m and 50 m transects respectively.

Previous analysis has shown that the single beam data is not always suitable for analysing the fine-scale behaviour of the nourishment. However, the large-scale morphological change can be examined perfectly well. Figures 3.9-3.15 demonstrate the morphological development of the Galgeplaat from May 2008 (before installation) up to and including December 2009. For each figure it is indicated whether it is a single beam, RTK-DGPS or combined measurement.

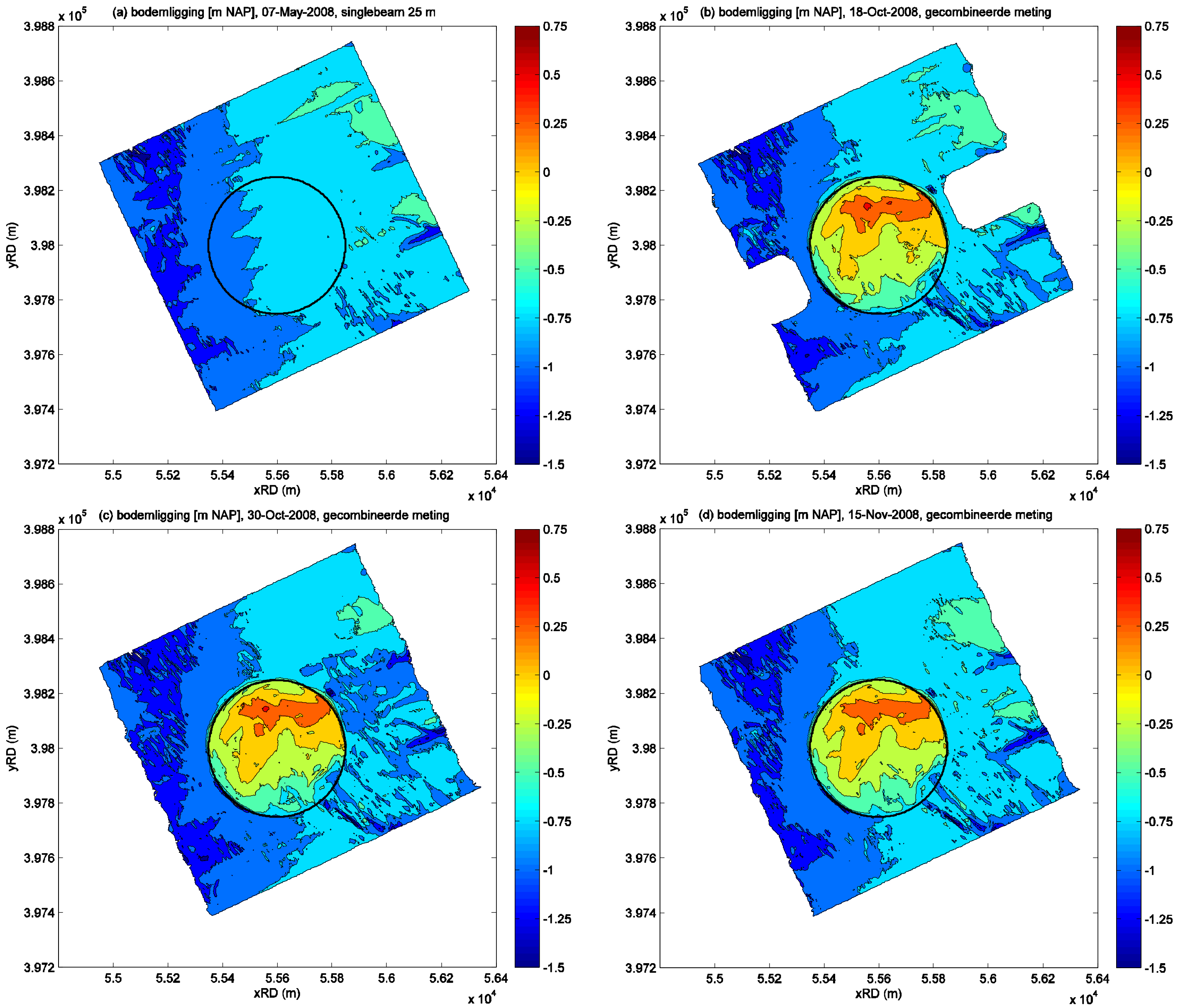


Figure 3.9 Morphological development of the nourishment based on single beam (25 m transects) and RTK-DGPS measurements, 7 May -15 November 2008. The black circle shows the initial contours of the nourishment.

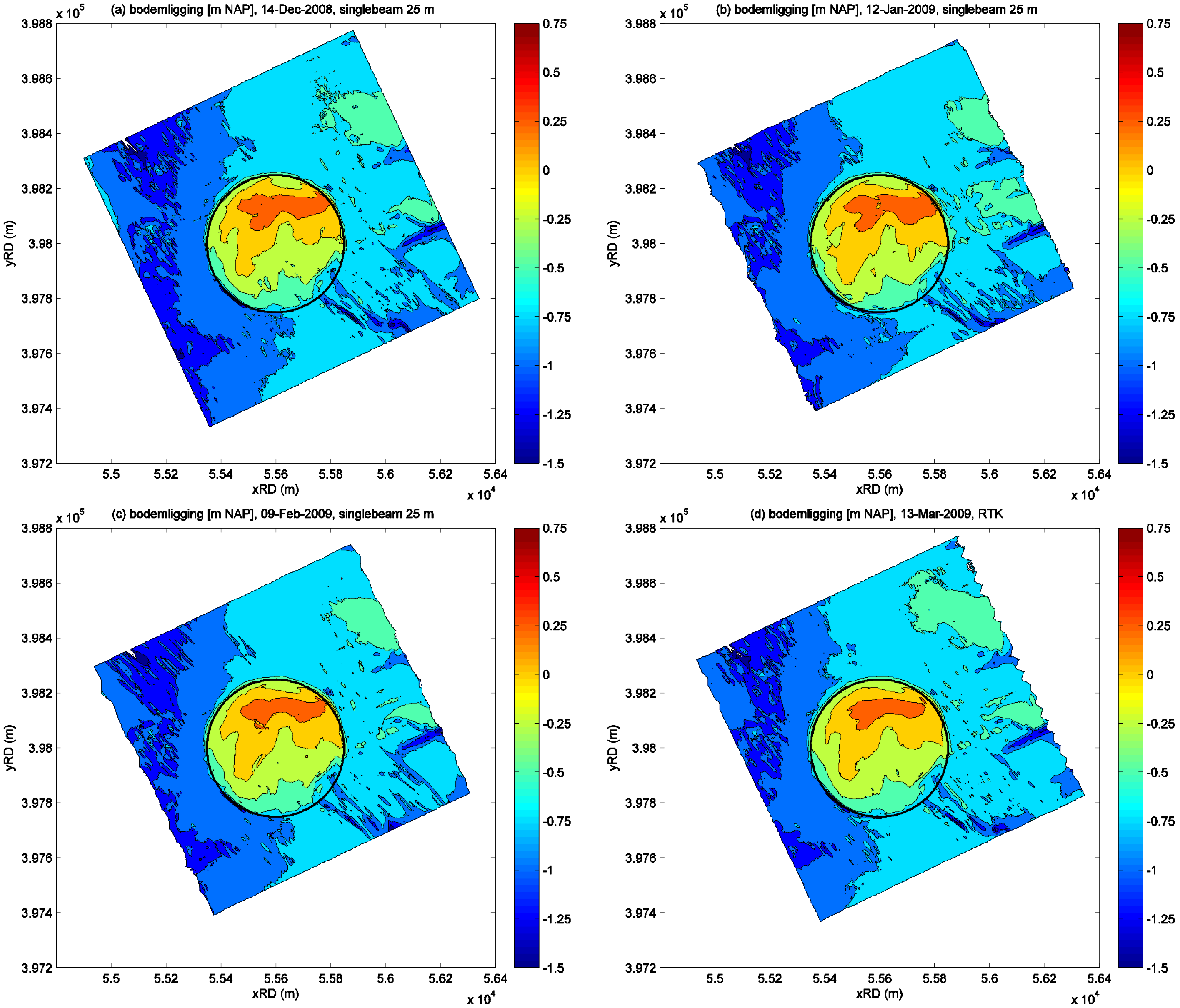


Figure 3.10 Morphological development of the nourishment based on single beam (25 m transects) and RTK – DGPS measurements, 14 December 2008-13 March 2009. The black circle shows the initial contours of the nourishment.

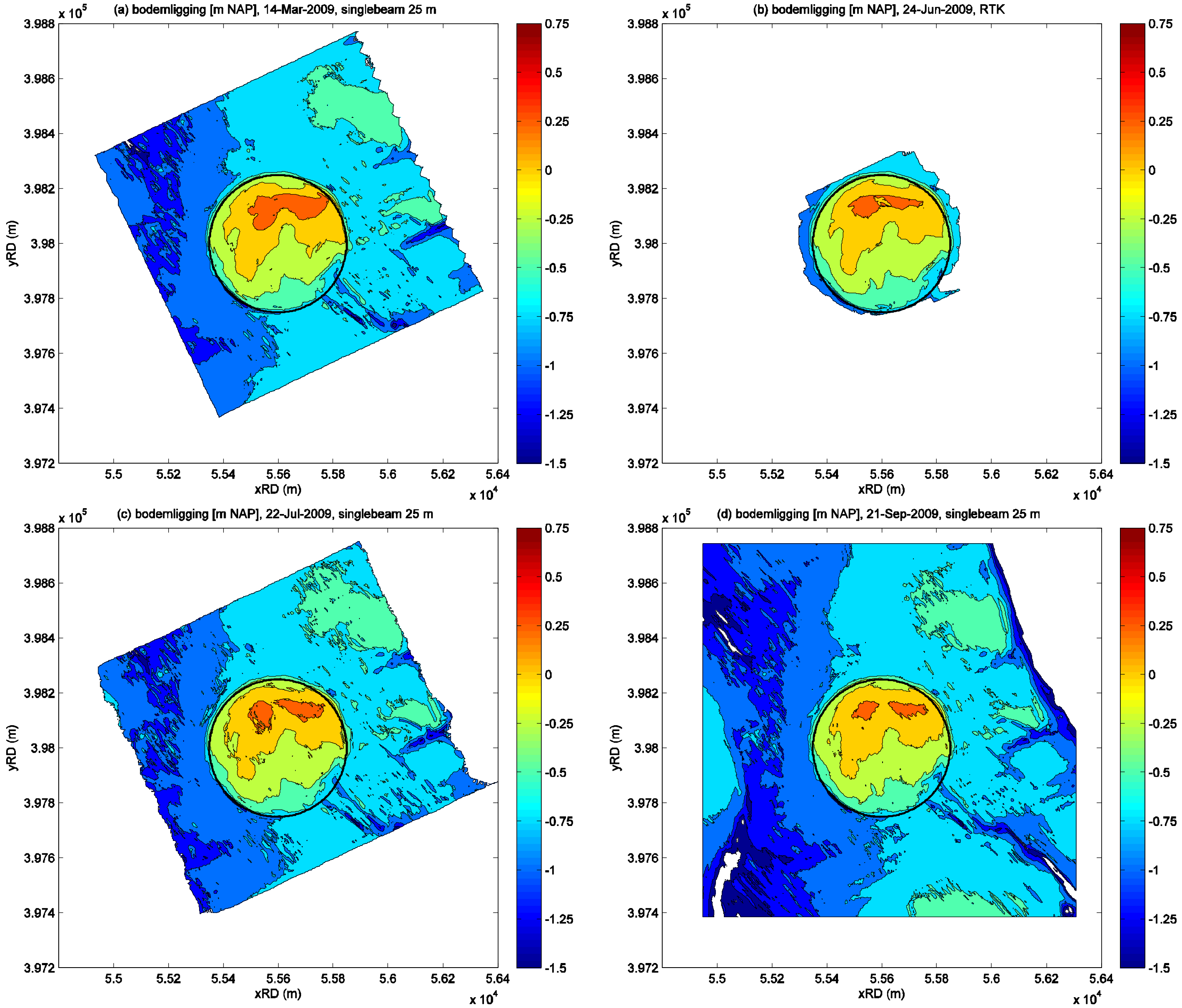


Figure 3.11 Morphological development of the nourishment based on single beam (25 m transects) and RTK-DGPS measurements, 14 March-21 September 2009. The black circle shows the initial contours of the nourishment.

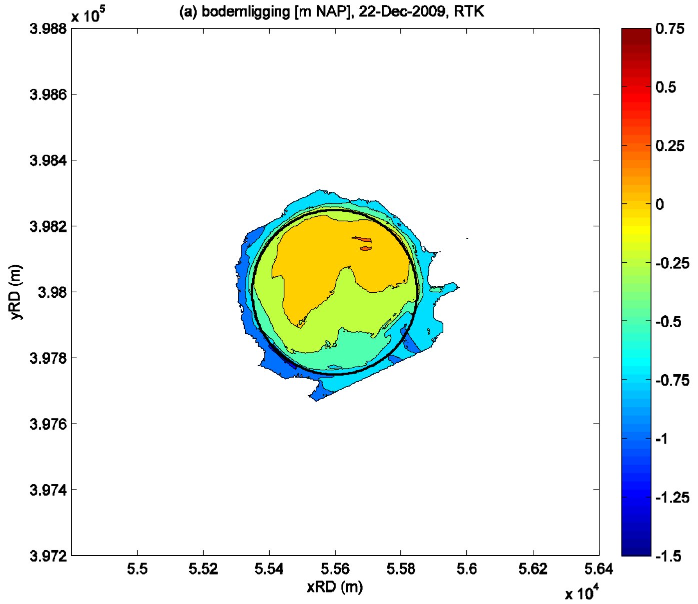


Figure 3.12 Morphological development of the nourishment based on single beam (25 m transects) and RTK-DGPS measurements, 22 December 2009. The black circle shows the initial contours of the nourishment.

These figures show how the bed level has been raised by the nourishment from approximately -0.5 m NAP to + 0.5 NAP on average. These measurements confirm the results formed by the SET measurement and profile measurements. The high, northerly part of the nourishment (> +0.25 m NAP) is eroding and at the end of December 2009 had almost completely disappeared. There is also obvious sedimentation along the northerly and especially the northeasterly edge of the nourishment. Apart from these two developments, the nourishment is relatively morphologically stable. This is also apparent from the cumulative sedimentation/erosion portrayed in Figure 3.13.

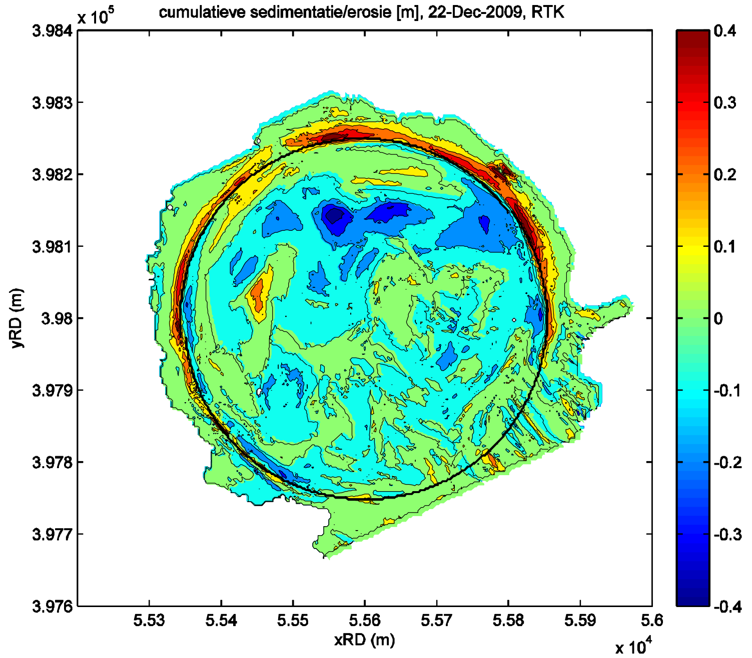


Figure 3.13 Cumulative sedimentation and erosion between October 2008 and December 2009

3.2.4 Change in nourishment volume

Figure 3.14 shows the volume changes in the area surrounded by the initial contours of the nourishment (almost 15 hectares). In particular the cubic volume based on the single beam measurements shows an unpredictable development, which is probably caused by systematic measurement errors. The three bed level measurements based on the RTK-DGPS measurements show a consistent trend, although it is worth noting that the volume decreases between March and June 2009 and is then followed by an increase. In general, the data seem to indicate a slightly downward trend in the sand volume; in total a couple of thousand cubic meters, or 1-2% of the nourished volume.

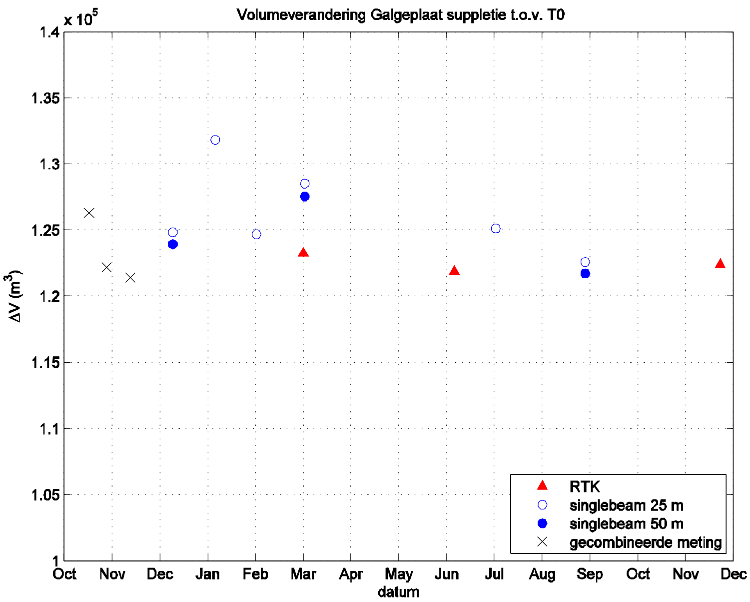


Figure 3.14 Change in volume in the nourished area compared with T0 (7 may 2008)

The spread of the different volumes gives an indication of the possible error margins. It is difficult to determine an exact value, as it is not known how large the systematic error in the single beam measurements is (regardless of the arbitrary error of approximately +/- 0.1 m) and how large the error is that occurs as a result of interpolation and the measurement resolution. The extent of the error of the volumes based on the RTK-DGPS measurements is estimated at a couple of thousand cubic meters.

A decrease of 1-2% of the nourished volume relates to circa 0.1-0.2 m of erosion. The erosion rate is therefore in the order of 0.1 m/year. This is the same rate as the average rate of erosion on the mudflats and intertidal flats of the Eastern Scheldt.

3.2.5 Morphological development of the intertidal flat around the nourishment

The question is not just how the nourishment area has developed, but also how the area around the nourishment has changed. Is the nourishment area able to feed the surrounding areas or not? Has morphological change occurred as a result of local hydrodynamic conditions whereby more or less sediment has accreted and/or eroded?

The bed levels along the profiles and at the SET locations show that material has been transported in a north-northeasterly direction, but that the transport is still minimal.

Using the single beam measurements over the 50 m transects the morphological impact of the nourishment can be studied for a larger area. Measurements from October 2008 up until and including September 2009 show that on this spatial scale there are no noteworthy bed level changes, with the exception of the nourishment itself.

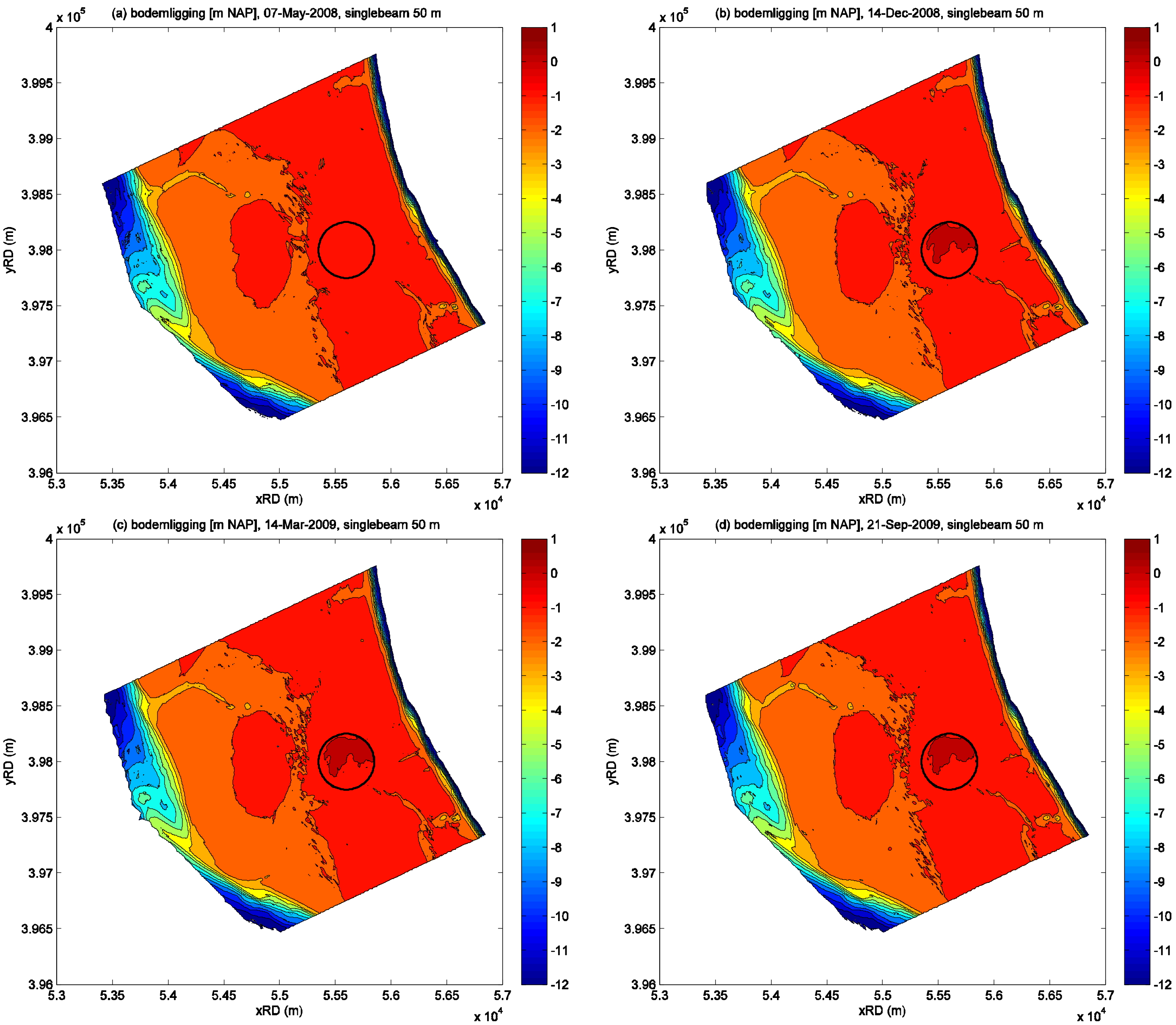


Figure 3.15 Morphological development of the nourishment based on single beam measurements (50 m transects). The black circle shows the initial contours of the nourishment.

The volume derived from concentric circles around the nourishment indicates whether changes have occurred. The volume from three circles around the initial contours of the nourishment, with a radius of 10 m, 50 m and 100 m larger than the initial contour, were calculated and compared with the T0 situation. The results are shown in the following table.

Table 3.2 Volumes (10^3 m^3) from various circles around the nourishment. The volume given is the difference with the T0 situation.

Date	Initial nourishment contour	radius 10 m larger than the nourishment contour	radius 10-50 m larger than the nourishment contour	radius 50-100 m larger than the nourishment contour
14-12-2008	124	3	1	2
14-03-2009	128	4	3	3
21-09-2009	122	4	3	3

It is apparent that slight changes have appeared. However, the question is whether these changes are really caused by the nourishment. Given the inaccuracy of the single beam measurements, the limited number of data points and the slight changes, it is not yet possible to draw conclusions from this information. Further monitoring and supplementary research are needed to show to what extent the bed level of the Galgeplaat outside the nourishment area has changed and if and how this is related to the nourishment.

The profile measurements (Section 3.2.2) are very important for this process, because they extend outside the nourishment area. It is important to make sure that the profiles always continue to beyond the visible transportation of the material of the nourishment. This will make it possible to 'follow' the nourishment and the area surrounding the nourishment.

The single beam measurements (25 m or 50 m transects) are not accurate enough for the so-far small changes. This means that having RTK-DGPS measurements covering the whole area is important. The RTK-DGPS measurement is presently primarily restricted to the original nourishment location. It is recommended that these measurements are extended in the direction that the nourishment is developing. This is demonstrated in the figure below. Based on the cumulative change between 2008 and 2009, the dotted line in the figure shows how far the RTK-DGPS transects would have to be extended in order to be able to track the development of the nourishment.

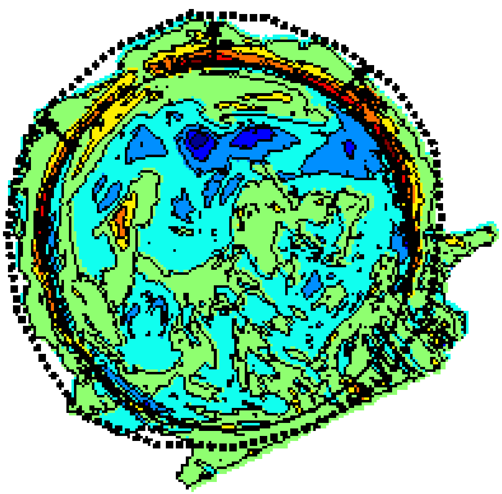


Figure 3.16 Recommended minimum surface of bed level measurements with the use of RTK-DGPS

3.3 Exposed area and duration of exposure

To determine the effect of the nourishment on the duration of exposure during the tidal period, the water level measurements at Stavenisse during 2008 and 2009 (see Figure 3.2) have been examined in combination with the bed level. It is assumed that the nourishment does not influence tidal propagation in the area. The duration of exposure was examined for several moments in time for an area slightly larger than the nourishment (circa 24 hectares) (Figure 3.17).

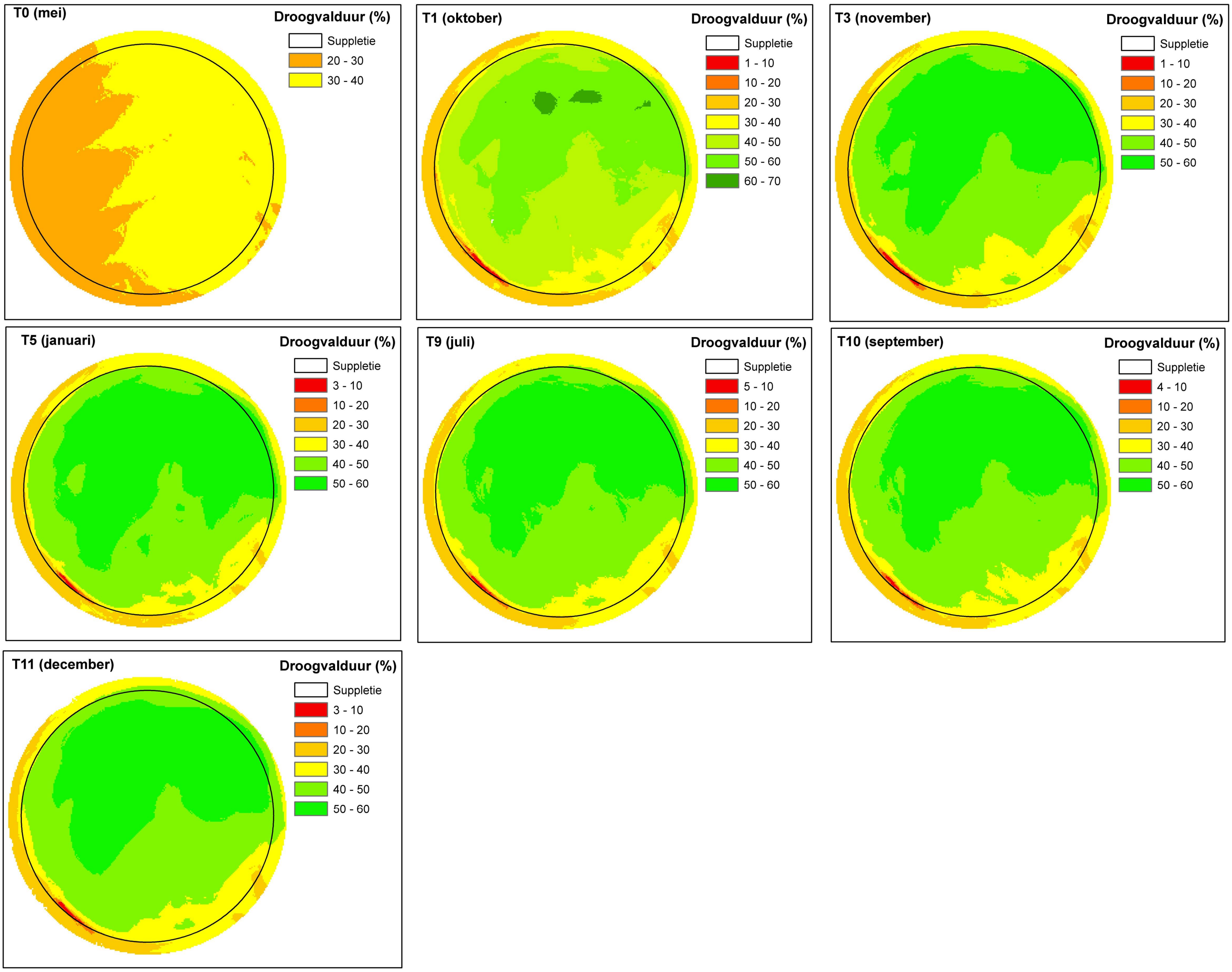


Figure 3.17 Development of the duration of exposure of the nourished area

The surface relating to the duration of the exposure is shown in Figure 3.18. As a result of the initial nourishment the exposure time increased (arrow 1) from roughly 30% up to 50 to 60%. After the nourishment was put in place it started levelling off, and therefore the exposure duration has decreased slightly again in the higher parts (arrow 2).

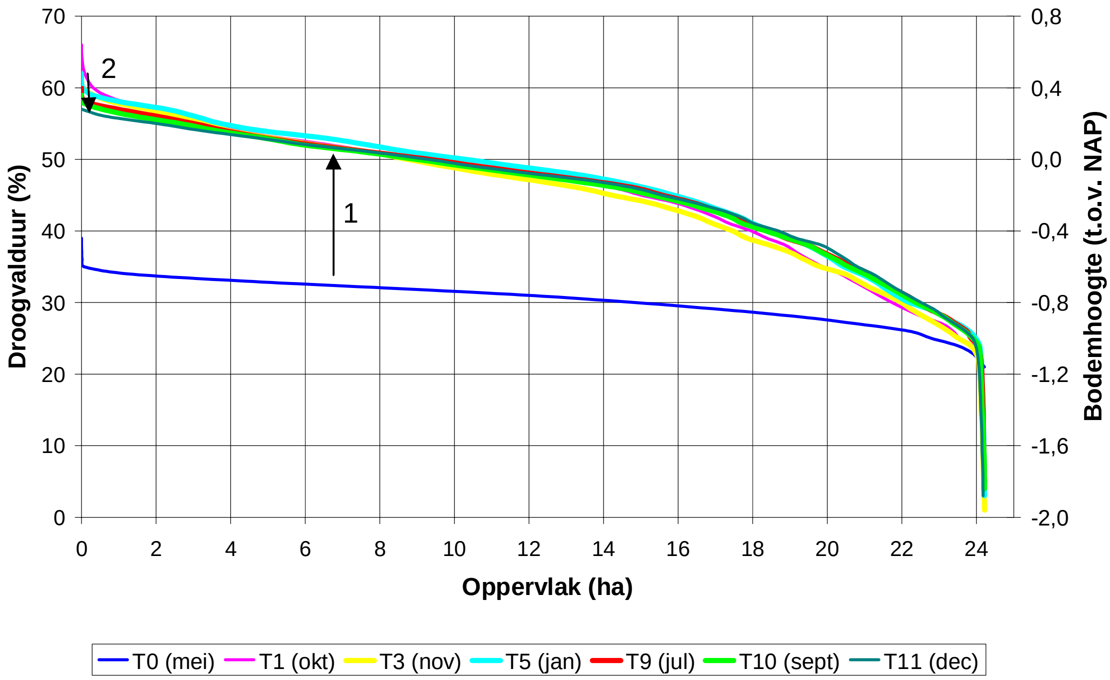


Figure 3.18 Development of the exposure duration after the nourishment was put in place

The following table shows the surface of the exposed areas. From this it can be concluded that the increase in area exposed when the water level is lower than 0.0 m NAP has remained virtually constant (circa 9 hectares). The erosion of the higher parts of the nourishment is clearly visible in the area that is only exposed when the water level is high. For example, the area exposed at +0.4 m NAP has increased by 0.3 hectares as a result of the nourishment (October 2008). In December 2009 the whole area is again covered at this water level.

Table 3.3 Exposure duration and exposed area as a function of the bed level

Bed level (m t.o.v. NAP)	Exposure duration (%)	Exposed area (ha)						
		T0	T1	T3	T5	T9	T10	T11
-1,7	1	24,2	24,2	24,2	24,2	24,2	24,2	24,2
-1,3	10	24,2	24,2	24,2	24,2	24,2	24,2	24,2
-1,0	20	24,2	24,0	24,1	24,1	24,1	24,1	24,1
-0,7	30	14,8	21,7	22,0	22,2	22,4	22,4	22,5
-0,4	40	0	18,0	17,5	18,5	18,5	18,4	18,7
0,0	50	0	9,1	8,7	10,3	9,0	9,3	9,3
0,4	60	0	0,3	0	0	0	0	0
0,8	70	0	0	0	0	0	0	0

At the nourishment location the intertidal flat remains exposed for longer. However the nourishment has not resulted in an increase of exposure duration in the surrounding areas. For this reason, the foraging time for birds has only improved locally.

3.4 Ecological development

The nourishment of the Galgeplaat was carried out in order to slow the erosion of the intertidal flat down and thus to prevent birds having insufficient time to forage. The nourishment can be viewed as a type of sand buffer. The hypothesis is that the sand will be dispersed from this sand buffer over the intertidal flat via natural transport processes and as a result the net erosion of the intertidal flat will be slowed down. In addition the objective is not only for the nourishment to function as a sand buffer but also that it is absorbed, as quickly as possible, into the ecological system of the intertidal flat. In this way the impact of the nourishment on the ecological system will be mitigated as much as possible.

In ecological terms there are two main questions with several sub questions. These questions are related to the objectives 1, 2, 4 and 5 defined in Section 1.2:

- What is the effect of the nourishment on the development of the surrounding intertidal flat?
  - What is the area of influence of the nourishment?
  - Is the duration of exposure of the intertidal flat increasing in this area?
  - Is the impact on the ecosystem in this area positive, negative or non-existent?
  - What preconditions must be made on the shape, location and execution to:
    - Enlarge or reduce the affected area?
    - Increase the duration of exposure of the intertidal flat in the affected area?
    - Increase or reduce the impact on the affected area?

- How quickly will the nourishment area become fully reintegrated into the intertidal flat ecosystem?
  - Which benthic fauna was present in the nourishment area before the nourishment took place?
  - How quickly is the benthic fauna recolonising the nourished area?
  - What is the development of the duration of exposure of the nourishment?
  - When will the birds begin to forage on the nourished area?
  - Which preconditions must be set on the shape, location and execution to enhance the recolonisation of the nourished area with benthic fauna and the foraging of birds?

3.4.1 Birds

The nourishment has now been completed and the question is whether the foraging opportunities have improved for the birds on and around the nourishment. This improvement is dependent on two factors: the exposure duration and the available food.

The first question was whether the birds are actually making use of the nourishment and/or surrounding area. This was investigated by bird counts carried out in October 2007 and 2009. In October 2007 the number of birds counted on the Galgeplaat was relatively low. Geene (2007) indicates that when the survey was carried out that there were not a particularly large number of birds present in the Eastern Scheldt. The highest density on the Galgeplaat was 13.8 birds per hectare. The average number of foraging minutes on the Galgeplaat was 2700 minutes/hectare. Previous surveys in 2006 on the Galgeplaat (90 to 700 meters west of the present surveying areas) show higher density levels (55.84 birds per hectare). Out of all the birds counted, the oystercatcher and the curlew were by far the most common.

The survey in October 2009 shows that the higher parts of the nourishment were being utilized very little by foraging birds. Indeed, for the whole nourishment area, the number of birds was very low (Geene and Goedbloed, 2009). The average number of birds per hectare on the nourishment is 1.36. Most of the birds counted were just outside the nourishment area. The average number of birds just outside the nourishment area is roughly the same as the average number of birds in 2007. Again, in 2009 the oystercatcher and the curlew were the most common, although there were fewer oystercatchers than in 2007.

The number of birds on the nourishment is so low that it can be concluded that the nourishment is not yet attractive to foraging birds. The reason for this could lie in the absence of benthic fauna. It is noteworthy that, despite the very low numbers of birds being observed on the nourishment area during the bird counts, during the field research many bird tracks were reported over the majority of the nourishment area.

The surveys are obviously a recording of a moment in time and therefore there is a chance that some of the birds were ‘missed’. However, the ARGUS-BIO station is continuously recording images which include the presence of birds. Based on these recordings a better picture can be made of the utilization of the nourishment by birds. The analysis of the images falls outside the scope of this report. Nevertheless in Chapter 4 a first trial test is shown of how data from the ARGUS-BIO station could be used.

3.4.2 Benthic fauna

In October 2007 an initial survey (T0) of benthic fauna was carried out on and around the location of the nourishment (Sistermans et al., 2008) followed by a second survey (T1) in 2008 (Sistermans et al., 2009) and a third survey (T2) in 2009 (Escaravage et al., 2009). For the last two measurements a number of sampling locations were moved, removed or added (see also Section 2.4) to enable a classification of ecotopes (on the advice of Dick de Jong).

It was apparent from the initial measurement in 2007 that the biomass in the centre of the sampled area (now the nourishment area) was the largest (locations 2, 3, 6 and 7) and was dominated by *Bivalvia* and *Gastropoda*, mainly the *Cerastoderma edule* (cockle) and *Hydrobia*. Since the nourishment was put in place in 2008, there has been very little biomass in this area and what is there is defined by the presence of *Gastropoda*. In 2009 the biomass in the nourishment area increased slightly but still did not reach the pre-nourishment level. The biomass in 2009 was not only defined by the *Gastropoda* but also by *Polychaeta* (sandworms and tube worms) and *Bivalvia* (Baltic Macoma). On the nourishment it is clearly visible that there is less biomass in the higher parts (locations 2 and 3) than in the lower parts which lie on the southern part of the nourishment (locations 6 and 7).

At the remaining sampling locations surrounding the nourishment, the changes in biomass compared with 2007 are far smaller and the division of classes has changed slightly. In 2007 and 2008 the biomass in the more eastern locations (locations 4, 18, 19 and 20) was mainly dominated by *Bivalvia* (cockles). In 2009 the proportion of *Polychaeta* (sandworms and tube worms) and *Gastropoda* at these locations had increased. In 2007, in the west (location 14) the area was dominated by *Polychaeta* (tube worms and white cat worms). In 2008 and 2009 *Bivalvia* (cockles and soft-shell clams) were also observed. In 2008, south of the nourishment (locations 13, 21 and 22) the biomass was principally dominated by *Bivalvia* (Baltic Macomas and cockles), together with a number of *Polychaeta* (sandworms and tube worms) and *Gastropoda*. In 2009 the ratio remained approximately the same, although *Malacostraca* were also reported.

The density of the benthic fauna shows a different picture of the benthic fauna division than the biomass, as it is not determined by the biomass of the individual which can vary considerably per species, but by the number of individuals. The density at the sampling locations in 2007 was the highest in the central part of the sampling area and was dominated by *Gastropoda*. In 2008 the density here was much lower and was dominated by *Gastropoda*, *Malacostraca* and *Polychaeta*, although the density was not divided equally over the sampling points. In 2009 *Bivalvia* and *Clitellata* also appeared.

In 2009, the division over the sampling points was also not equal. In the southern parts of the nourishment, which are lower, there were more species than in the northern, higher sampling locations. In general, the density increased in 2009 in relation to 2008 but did not reach the level of 2007. In the less sandy areas, the density of *Gastropoda* was much lower and other classes such as *Polychaeta* and *Malacostraca* comprised a substantial proportion of the benthic fauna. The observed density and biomass on and around the nourishment location was 3-4 times lower than on other locations in the Eastern Scheldt.

Using a multivariate analysis (MDS) the similarity between the benthic communities at the sampling locations was examined for 2007, 2008 and 2009. The analysis showed that in 2007 all the locations were very similar in terms of community. After the nourishment the benthic communities changed considerably at the nourishment location. The survey in 2009 shows that the benthic communities were slightly more similar to those of 2007. The trends observed in the biomass, together with the density and number of species, indicate a gradual recovery of the benthic communities in the nourishment area. However, the length of time it will take for a complete recovery of the benthic fauna cannot be determined based on the current dataset (Escaravage et al., 2009).

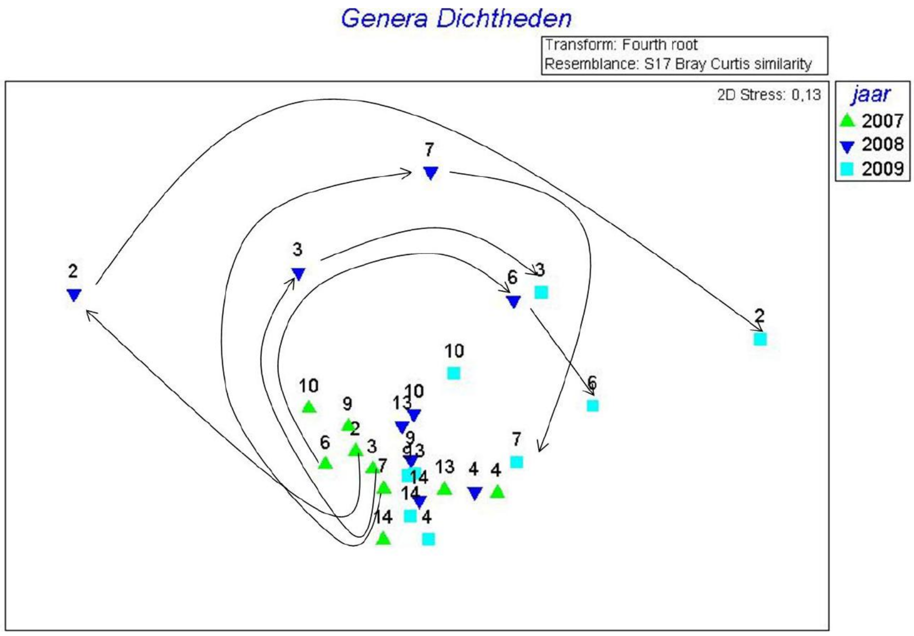


Figure 3.19 MDS diagram of the similarities (Bray-Curtis coefficients) between benthic communities (genus density) found in nine locations during the three sampling campaigns in 2007, 2008 and 2009. The lines between two observations have been added to the diagram to make it easier to read. However, the actual development between the observations is not known (Escaravage et al., 2009)

3.4.3 Sediment composition

The sediment composition is an important factor in the development of the benthic fauna on the Galgeplaat. The composition of the sediment in 2007 in the area around the nourishment area is quite uniform. The median grain size consists mainly of fine sand, together with smaller amounts of very fine and medium sand. The proportion of silt is not higher than 7%. In the location of the nourishment the sediment is somewhat coarser (D50 ≈ 191 ɥm) and sandier than outside the location of the nourishment (D50 ≈ 160 ɥm – 189 ɥm). Appendix C gives the sediment composition and grain size per year for all the sampling locations.

Since the nourishment was put in place the sediment composition has remained almost the same. However, the median grain size on the nourishment itself is slightly higher, from an average of 191 ɥm before the nourishment to 215.3 ɥm afterwards. This was expected, given that the nourished material consisted almost entirely of coarser sand (D50 ≈ 180-250 ɥm) from the Witte Tonnen Vlije and the Engelsche vaarwater channels (Figure 3.20).

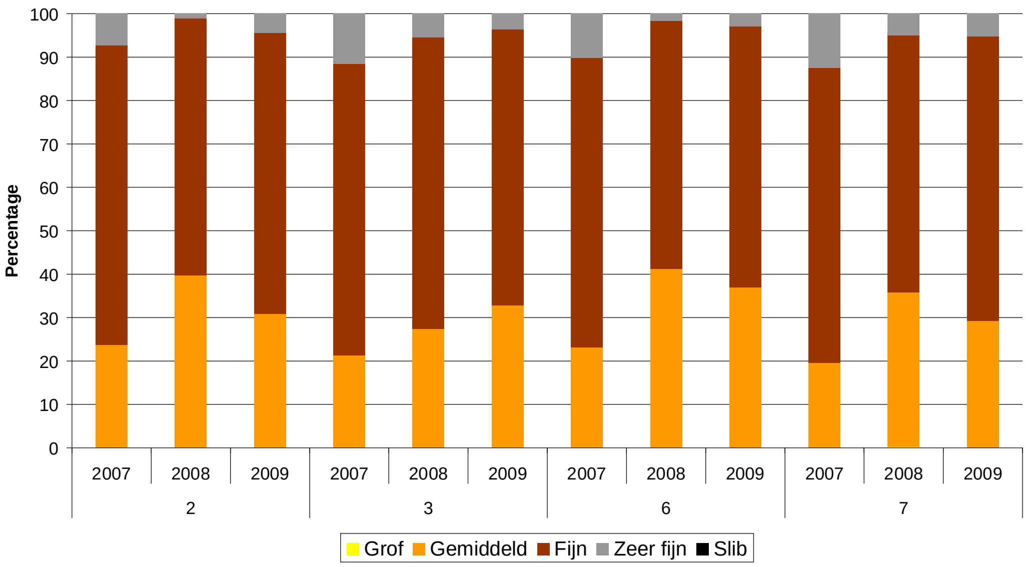


Figure 3.20 Sediment composition at the nourishment location. (Coarse, Average, Fine, Very fine, Silt)

The sediment composition of the bed around the nourishment appears to have changed little over time. The median grain size on the south side of the nourishment is circa 183 ɥm. On the north side of the nourishment the median grain size is slightly higher at circa 189 ɥm and on the east side of the nourishment the median grain size is around 160 ɥm (see figures 3.21-3.23).

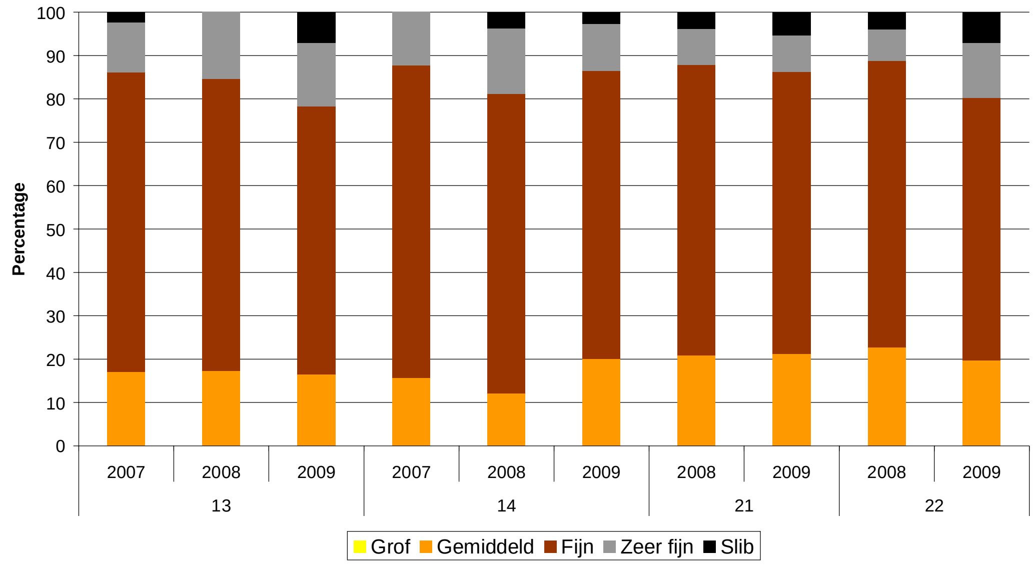


Figure 3.21 Sediment composition on the south side of the nourishment location (Coarse, Average, Fine, Very fine, Silt)

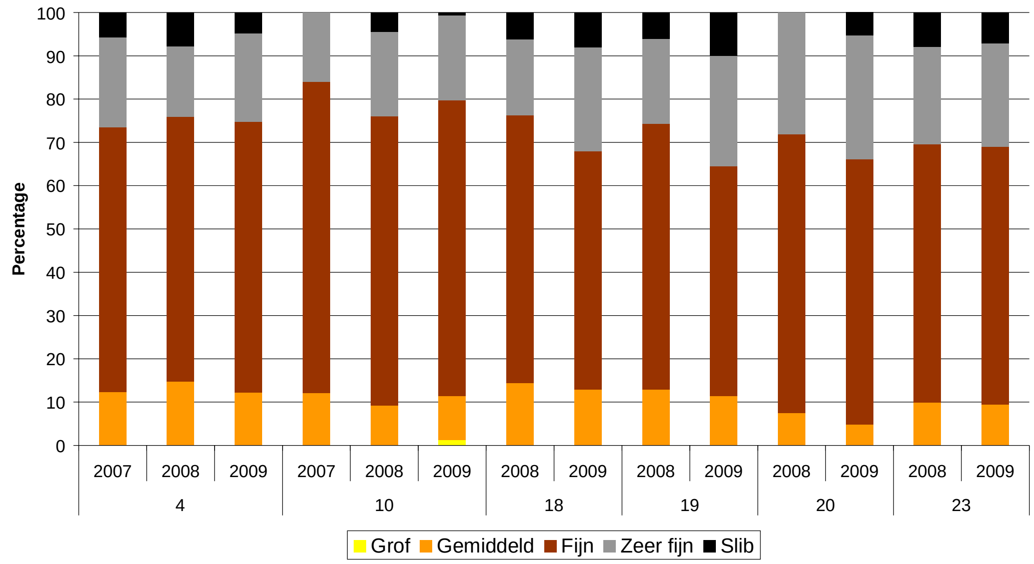


Figure 3.22 Sediment composition on the east side of the nourishment location. (Coarse, Average, Fine, Very fine, Silt)

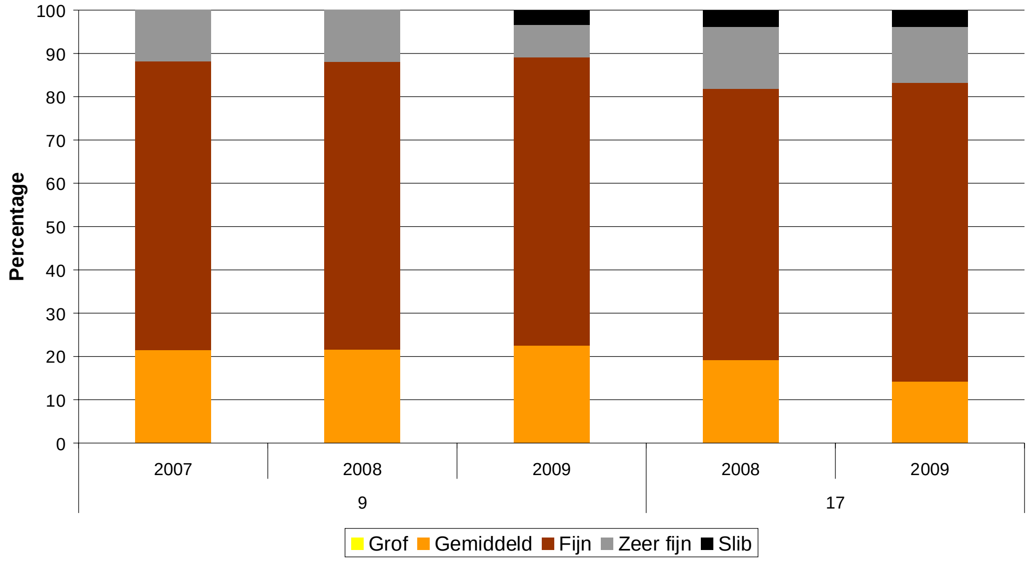


Figure 3.23 Sediment composition on the north side of the nourishment location. (Coarse, Average, Fine, Very fine, Silt)

3.4.4 Productivity of the mussel beds

The dredging and land drainage activities have led to a temporary and localised increased concentration of suspended matter in the water column. The analysis of the mussels which were brought by the mussel growers into Yerseke harbour and a comparison with historical data show no significant effect of the nourishment on the quality of the mussels collected. In addition, the monitoring of the development and growth of the mussels and in the cages in the mussel beds nearby the Galgeplaat shows that the dredging and nourishment activities has not caused any negative effects on the growth or development of the mussels (De Mesel et al., 2009).

4 ARGUS

4.1 The objective of the ARGUS-BIO station on the Galgeplaat

The ARGUS-BIO station on the Galgeplaat is not the only location using this technique. Monitoring of morphological developments using ARGUS stations has been taking place for many years in various locations (see www.wldelft.nl/argus). There are also other places where cameras have been used to survey birds. The reasons for using cameras are that the birds are often in inaccessible places and they are not disturbed. There are several webcams (mainly for the purpose of education) in the Netherlands and cameras installed by Imares on the Balgzand and the Razende Bol in the Wadden Sea area.

4.2 Morphological monitoring with ARGUS

In order to investigate morphological changes the bed level is monitored. Normally these measurements are carried out in the field with RTK-DGPS measurements (on foot) at low tide or with an echo-sounder from a boat during high tide. The time-consuming nature and required equipment make these types of measurements relatively expensive and as a result they are only carried out once a month at most. It is not possible to carry out these measurements on an everyday basis. The influence of a storm on the nourishment could therefore be ‘missed’. Previous studies have shown that the response of a beach to a storm takes place within a few days (Uunk et al., 2009). Therefore, an ARGUS station has been placed on the Galgeplaat in order to be able to monitor the bed level at a high frequency.

The advantages of the ARGUS monitoring are the high measurement frequency over a relatively large area and the low costs of obtaining data. However, the optical measurements are dependent on meteorological conditions and the accuracy is slightly lower than physical field measurements. Nevertheless, in order to determine morphological trends this method is extremely suitable and the resulting measurements of the bed level seem to be accurate enough for many applications.

Bed level measurements are often used to define Coastal State Indicators (CSIs) in order to establish the morphological behaviour. This can be defined volumes or coastlines, which are relatively insensitive to interference in the measurements and which give a trustworthy report of the state of the coastal system. Other, simpler measures of a morphological system can be the position of certain contours or the incline of the intertidal area.

4.2.1 Mapping shorelines using video pictures

In order to determine the bed level from ARGUS images, the shoreline is ‘mapped’. As the tide goes in and out and has a known height, the shoreline can be identified in the video images and translated into contours of the bed level. These contours can be interpolated to determine the bed level.

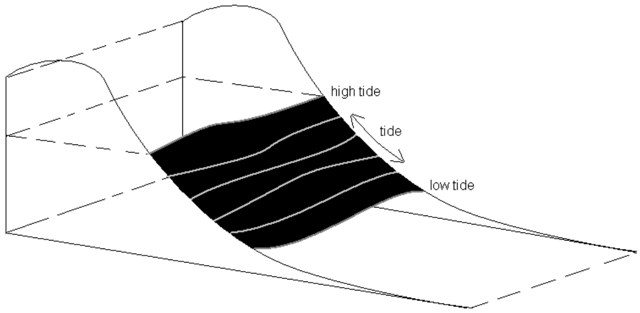


Figure 4.1 Mapped shorelines which are interpolated in order to determine the bed level

In order to convert the shoreline from an ARGUS image into coordinates (in meters) we use so-called ‘geometric solutions’. This photogrammetric technique allocates every pixel in the photograph to an X, Y and Z coordinate in the coordinate system. However, because only two pixel coordinates (U and V) can be obtained from a picture (a photograph is a flat 2D area), it is necessary to determine the Z level using a different method. Usually the Z level is determined using the measured water level (if possible including the wave progression). In this way all the X, Y and Z coordinates are known and the bed level can be determined.

Mapping shorelines in order to determine the bed level has often been carried out at the various ARGUS stations around the world. A tool has been developed called the Intertidal Beach Mapper (IBM), which is part of the ARGUS Runtime Environment (ARE) analysis software. The IBM makes it possible to detect shorelines in an ARGUS image semi-automatically.

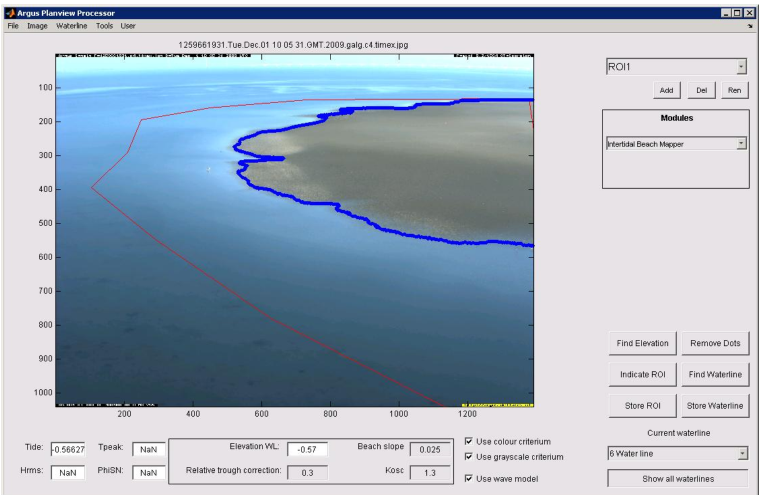


Figure 4.2 The Intertidal Beach Mapper tool

The calculation method clusters the pixels’ values (Hue, Saturation, Value) within a manually defined ‘Region of Interest’ (ROI). In this way a difference between ‘wet’ and ‘dry’ pixels can be distinguished. The transition between these two types of pixels is the shoreline. Afterwards it is possible to manually remove incorrectly detected shorelines (or parts of them) or add shorelines. The mapped shorelines are then interpolated onto a grid in order to achieve the real bed level, which can be used in further analyses.

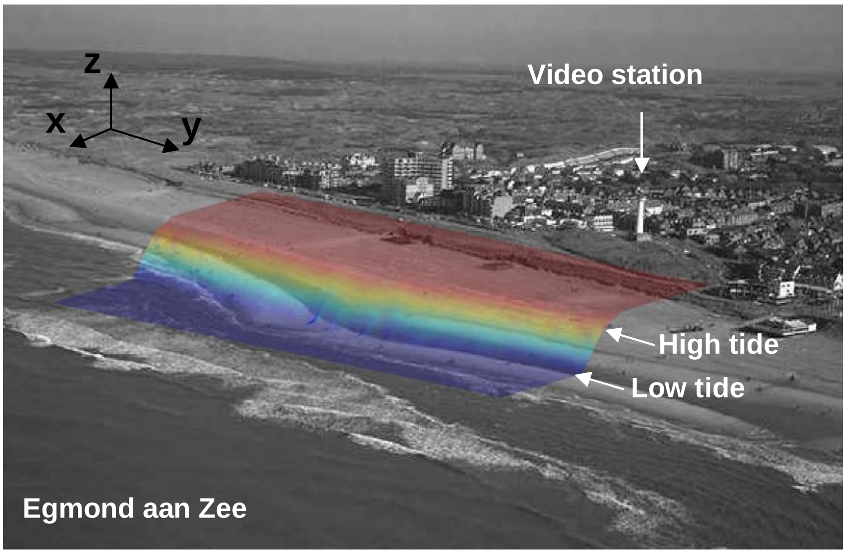


Figure 4.3 Example of an interpolated intertidal seabed as a result of mapped shorelines

It is a lot of work using the IBM to gather frequency data in order to establish the morphological changes on a daily basis. Therefore, the Automatic Shoreline Mapper (ASM) has been developed which can map the shoreline automatically and check the quality against the expected bed level. The ASM uses the same technology as the IBM but automates the determination of the 'Region of Interest' and the exclusion of incorrectly detected shorelines. The ASM has already been successfully used on the Dutch coast (at Egmond aan Zee) and also has potential for the Galgeplaat.

4.2.2 Mapping the Galgeplaat

Using the technology described above, shorelines have been mapped and converted into bed level maps of the Galgeplaat for different periods. Creation of these maps is still relatively time-consuming so given the short time available in this study only a few photographs have been converted into a bed level map.

To validate the bed level map derived with the ARGUS station, two dates were selected on which the shoreline is mapped and the bed level is measured in the field (bed level A1 and A4 in Table 4.1). In addition, two interim dates were selected to derive a morphological trend (bed level A2 and A3 in Table 4.1).

Table 4.1 Dates of available ARGUS bed level maps for the Galgeplaat

Reference date	ARGUS bed level map	Bed level field measurement
08-06-2009	A0 (deel)	
22-09-2009	A1	T10
01-11-2009	A2	
07-11-2009	A3	
22-12-2009	A4	T11

In order to do this one day is selected for which the shorelines are mapped and converted into a bed level map. If there are more adjacent days for which shorelines are available (for example, due to automatic mapping) then normally these extra days are used (2-3 days) for the interpolation into a bed level map. This results in a better coverage of the bed, but averages out any possible changes within these days. However, it is not expected that this would lead to significant variations in the case of the very gradually changing morphology on the Galgeplaat.

The mapping of shorelines to determine the bed level can only be done in areas in which the (tidal) shoreline is visible to the cameras. If there is a large intertidal area and the cameras are placed sufficiently high then the shoreline is almost always visible, except at night or during bad weather. In the case of the nourishment, the shoreline on the southern side (where the ARGUS station is situated) is clearly visible and the west and eastern sides can also be seen reasonably well. However the north side of the nourishment is invisible to the cameras and therefore the bed level (i.e. incline) on the northern side cannot be mapped.

The standard recording frequency of a typical ARGUS station is 30 minutes, which is normally sufficient to map an intertidal beach. However, in the case of the Galgeplaat, the height of the nourishment is small so the entire intertidal flat is completely under water within a few hours. Therefore with a recording frequency of 30 minutes only 2 or 3 suitable shorelines can be recorded. This is insufficient and therefore the Galgeplaat ARGUS station has been fitted with a system that increases the frequency of measured water levels at the station to 5 minutes during the inundation period of the intertidal flat. This produces sufficient images to properly map the bed level. Outside the inundation period, the recording frequency is 30 minutes in order not to obtain unnecessary data.

The degree of detail of the bed (for example, small canals on the nourishment) depends on the frequency that the shorelines are mapped during a tidal period and the quality of the photographs. When many shorelines are mapped, the interpolation into a bed level can be carried out with a reduced level of filtering and more details will be visible.

At the moment, the water levels used in the image processing are determined on the basis of the tidal measurements at Stavenisse and not locally at the Galgeplaat. The water levels in the Stavenisse vary slightly from the water levels on the intertidal flat. Therefore the vertical level of the mapped shorelines can vary slightly from reality and it might be necessary to correct these water levels later on in order to determine a more accurate bed level.

In addition, it has been shown that during ebb tide, the water leaves the nourishment and intertidal flat more slowly than when it is rising during high tide i.e. there is tidal asymmetry over the flat. This asymmetry indicates that there will be greater variation in the visible water level in the pictures (compared to the water levels at Stavenisse) during ebb tide than during flood tide. In addition, during ebb tide the shoreline is more difficult to see because the upper lying part is still wet and hence more difficult to distinguish. Thus it is recommended that the shorelines are mapped whilst the water is rising instead of retreating.

4.2.3 Validation of mapped shorelines for the Galgeplaat

The bed level maps obtained from ARGUS were compared with the field measurements in September and December 2009 for a number of transects over the nourishment (Figure 4.4). It is noted again that the northern side of the nourishment is invisible to the ARGUS cameras and therefore the bed level on the northern side cannot be determined.

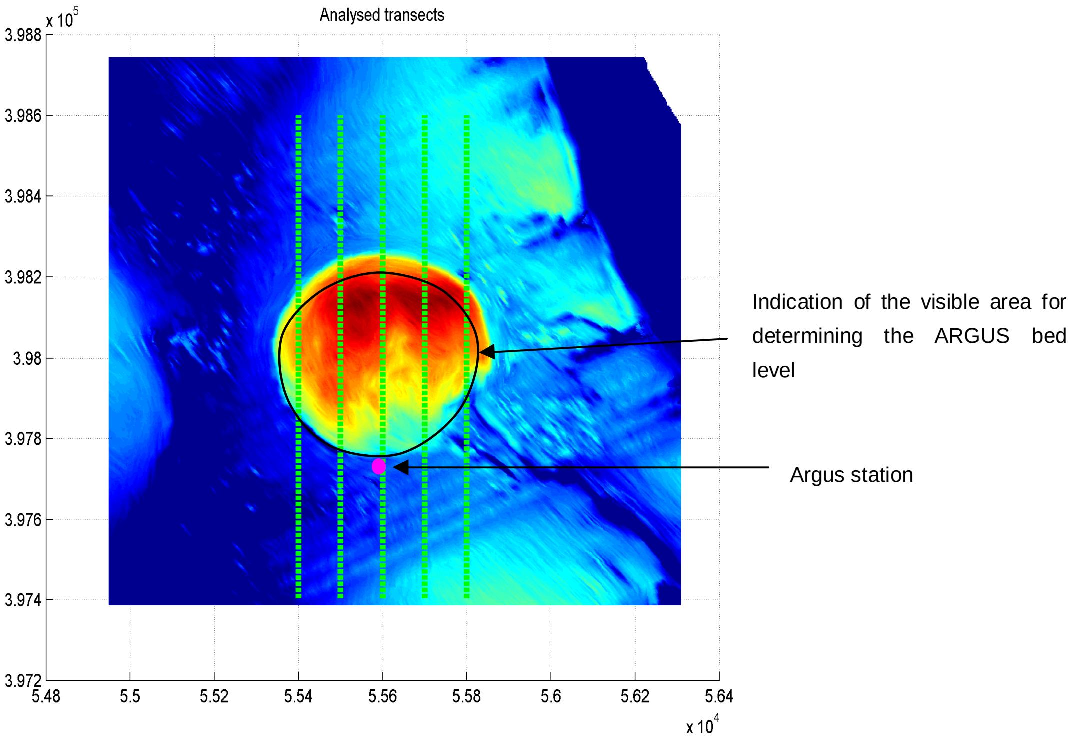
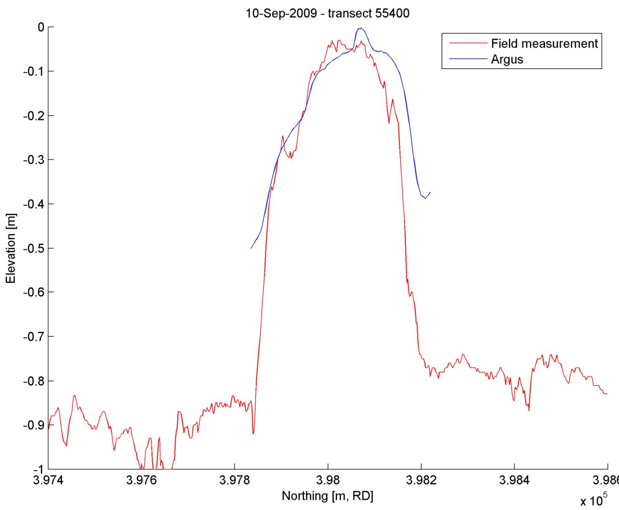
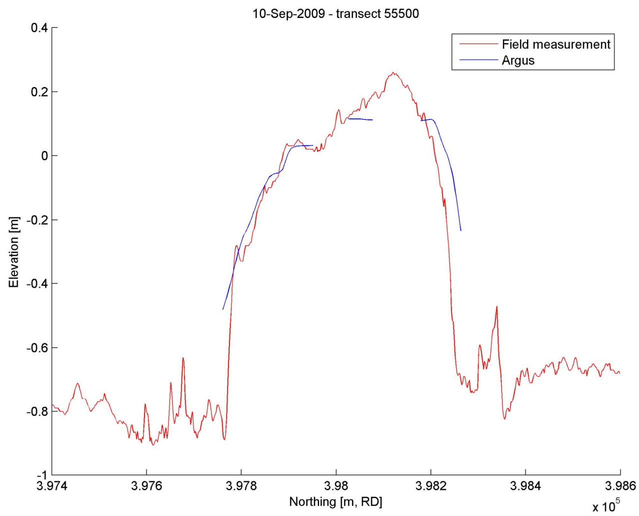


Figure 4.4   Analysed transects (dotted green lines).

The comparison for these transects for September is shown below.





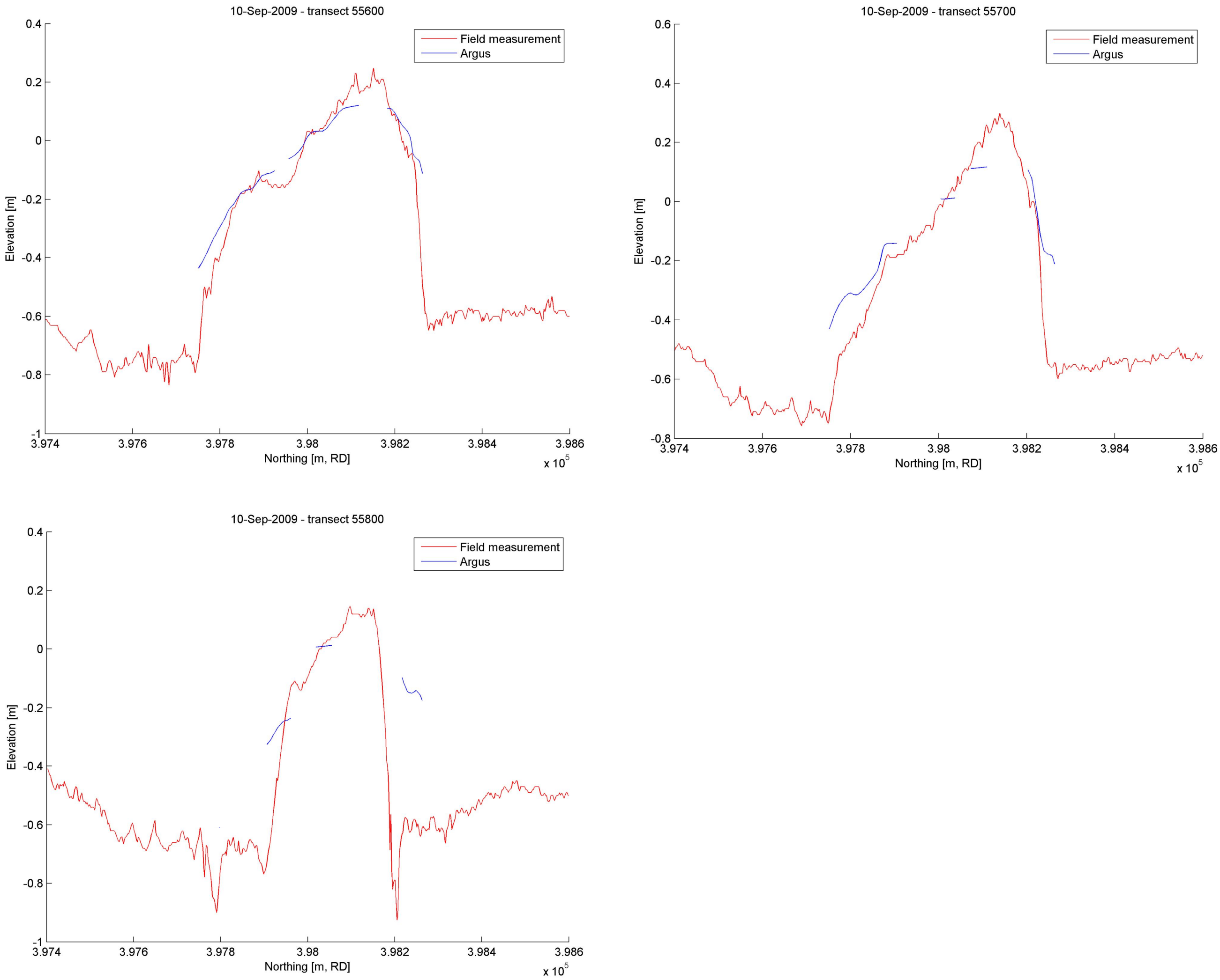


Figure 4.5 Validation of ARGUS bed level in September 2009

The similarity between the field measurements and the ARGUS bed level in September for transects 55500 up to and including 55700 are reasonably good although there are data gaps for some places on the ARGUS bed level. As indicated earlier this can be improved by interpolating the seabed data over several days. The ARGUS bed levels are constructed using an interpolation method that includes a filter in order to minimize interference. This results in a smoother seabed than when measured with a single beam (or RTK-DGPS).

A similar comparison of the 5 transects (as given in Figure 4.4) between the bed level measured in the field and the ARGUS bed level was carried out for December 2009 (see Figure 4.6).

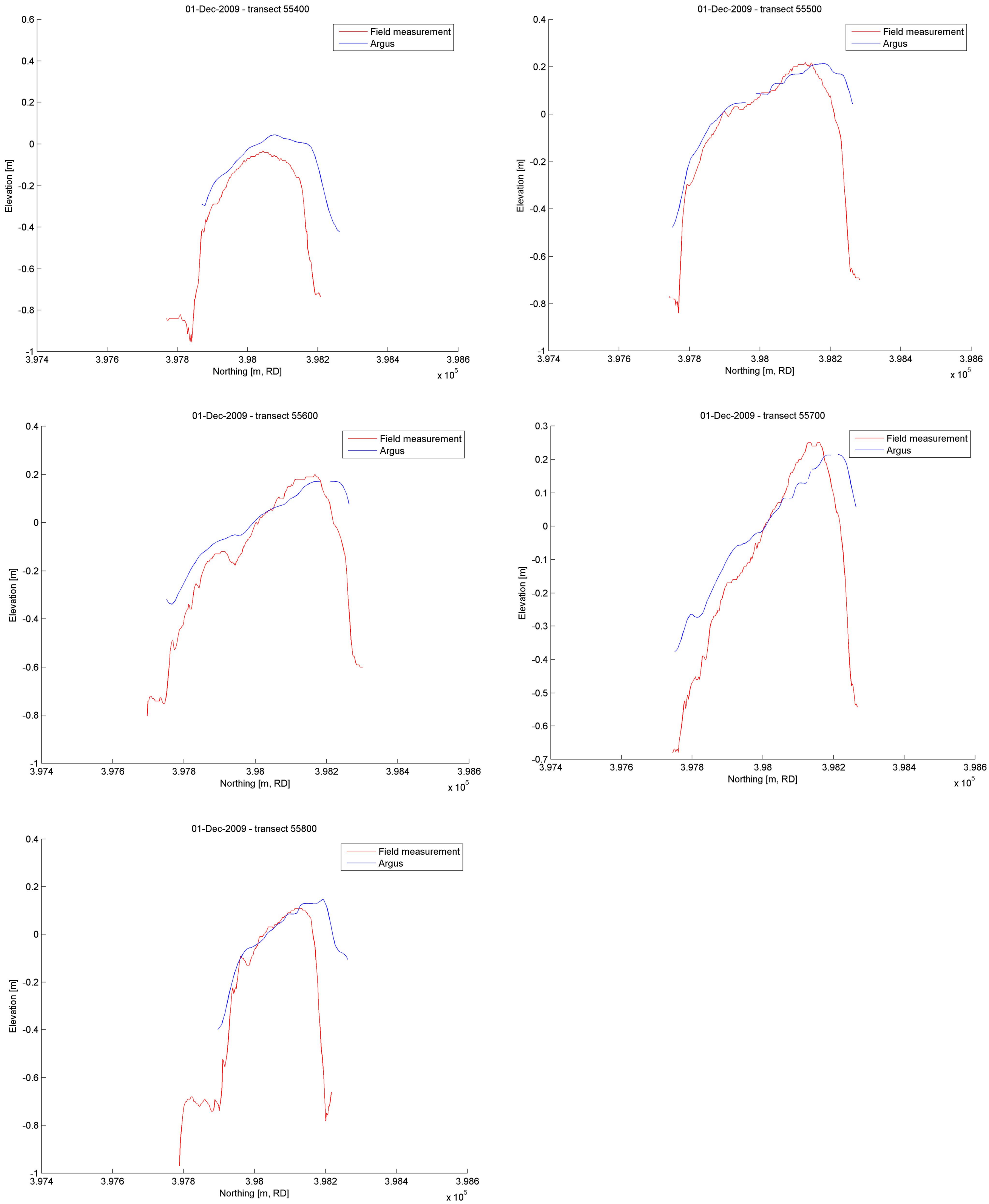


Figure 4.6 Validation of ARGUS bed level in December 2009

For this period it can be seen that the bed profiles from both the ARGUS images and field measurements are more similar. However, in transect 55700 it can be seen that the ARGUS bed level shows a gentler slope than the field measurement and that the peak of the profile is also further to the right. These differences are caused by differences in water levels at the Galgeplaat and Stavenisse. The geometric solution could also have caused a variation here because the camera could have moved. When the camera position is changed, a new geometric calculation needs to be determined in order to connect the pixels in the picture to the correct X, Y and Z coordinates; an incorrect calculation can lead to a distortion of the profile.

It can be concluded from the comparison of the bed level measured in the field and bed level derived from the ARGUS images in September and December that ARGUS has a close qualitative resemblance to the field data. Given the variations between the ARGUS bed level and the measured bed level are consistently very similar, it is expected that these variations are caused by varying water levels or inaccuracies in the geometric solution and not just by interference in the various measurements. This needs to be improved for an actual morphological analysis so that the data can be used in a relative sense (morphological trends) as well in a more absolute sense (as a direct measurement of the bed level).

4.2.4 First morphological results

The various ARGUS bed levels can be used to analyse the morphological behaviour of the nourishment for any desired period.

In September and December a field survey took place. Based on the ARGUS images two new bed levels are derived at dates in between (A1 – A4 in Table 4.1). These ARGUS bed levels show that the nourishment has not changed a great deal and that the morphological changes are developing slowly. The nourishment is moving slightly northwards (i.e. on the right in Figure 4.7), the incline is lower and the maximum height is reducing. This is in line with the results from the field measurements.

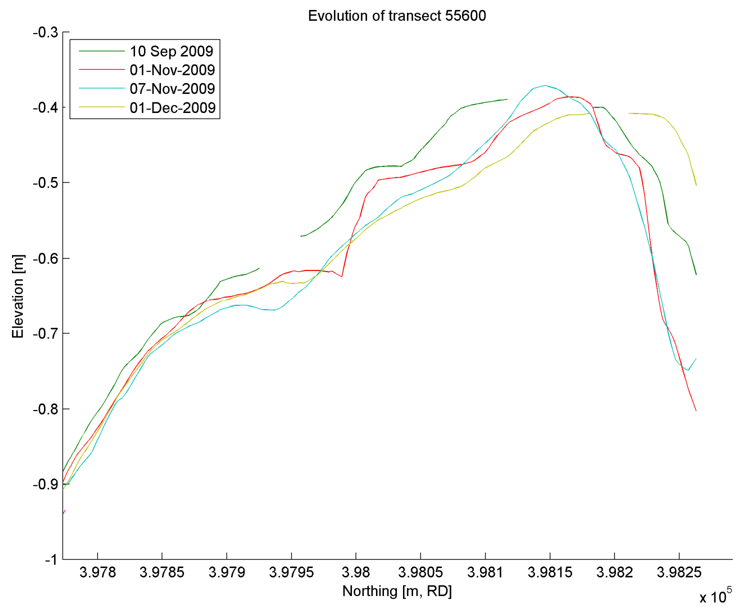


Figure 4.7 Evolution of the bed level of a transect (55660) for the Galgeplaat nourishment over time (September-December 2009)

Despite the fact that these interim bed levels showed no great changes in November, it does show that the nourishment is constantly moving. Above all, ARGUS offers advantages in the frequency and timing of available data for the Galgeplaat. For example, when storm conditions cause fast and significant morphological changes then these can be shown by ARGUS. At the moment, there are no mapped ARGUS images available for analysis of the storms that took place in the last year.

4.3 Ecological monitoring with the ARGUS-BIO station

The daily monitoring of other biota (i.e. diatoms, macroalgae, oyster beds and sandworms) using a fixed and movable camera on a station is new, as far as is known. This is already being done using aerial or satellite photographs, but these methods do not give a daily picture. In the near future, the University of Utrecht in the Netherlands is going to place a number of fixed cameras (probably 4-5) in the Wadden Sea for integrated monitoring of morphology and biota. Knowledge and experience will be exchanged between the parties involved.

4.3.1 The ARGUS-BIO camera

The camera for ecological monitoring is a movable monitoring camera (see Figure 4.8). The camera can turn 360° and has an adjustable tilt angle and zoom lens with an autofocus and 18x optical zoom[4]. The camera stands on a pole in a protective housing on the corner of the platform at an elevation of +16.825 m NAP and has been operational since 31 July 2009.

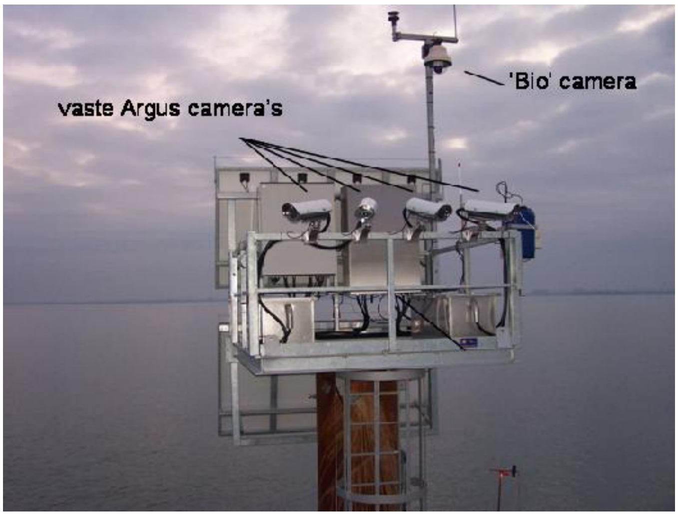


Figure 4.8 Platform with ARGUS cameras and the moveable ARGUS-BIO camera

The system is programmed such that the camera photographs the entire area around the pole when the intertidal flat becomes dry and there is sufficient light. The area that the ARGUS-BIO camera covers is divided into seven circles of various radii (see Figure 4.9; only 4 of the 7 rings are shown). First the smallest circle is photographed with a fixed zoom and tilt settings. Then the ARGUS-BIO camera adjusts to a slightly flatter angle and photographs the second circle with the necessary zoom, and so on. The pictures are sent to the Deltares server in Delft for storage and analysis.

[4] *f = 4.1-73.8 mm, horizontal optic angle 2.8°-48° and 0.5 MP (704 x 576) ¼" CCD and a shutter speed of 1/10000 to 1s. The maximum frame rate for video is 25-30 fps for all resolutions in Motion JPEG.*

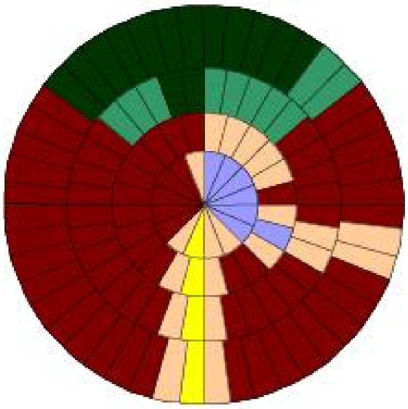


Figure 4.9 Schematic diagram of the innermost four circles of the PTZ camera. Ratios and surfaces are not to scale. Dark green = nourishment, light green = perimeter of the nourishment, dark brown = intertidal flat, light brown = intertidal flat with part of platform, yellow = camera post, blue = platform (De Mesel and Ysebaert, 2009)

4.3.2 Images of the biota on the Galgeplaat

The ARGUS-BIO camera provides pictures of the biota present (see Figure 4.10 and Figure 4.11). Currently not all the photographs are usable, as for example, when there is too much water on the intertidal flat, it is too dark or there is too much glare, there are water drops sitting on the lens or the lens is tilted too far causing blurred pictures (this last example is only true for the movable ARGUS-BIO camera).

Figure 4.10 Fixed ARGUS picture (C4, western side of the nourishment). In the distance there are large oyster beds and on the left smaller beds, partly under water. The green on the nourishment is caused by macroalgae. A few birds can also be seen.

Figure 4.11 Examples of pictures taken by the ARGUS-BIO camera: birds, macroalgae, sandworm tracks and clumps of oysters (excerpts, various scales).

The birds are the most visible, but oyster beds and macroalgae can also be seen. The visibility of diatoms varies considerably depending on the quantity, whether they are covered by a layer of water and the amount of light. Sandworms tracks (holes and casts) are visible on photographs close to the station. Further away they are difficult to distinguish form other bed forms. Seals have not yet been seen, but not all the photographs have been examined yet (there are many thousands!) Given the scope of this report and the present analysis methods of the pictures of the ARGUS-BIO camera, it is not possible to confirm the presence of biota. Meanwhile, in order to give an idea of what is possible, we will show two trial tests.

1. The use of the nourishment by birds
2. The coverage of the nourishment by macroalgae.

Use of the nourishment by birds

An initial analysis of images taken over four days (1 and 2 August and 28 and 30 September 2009) shows that birds prefer to sit on the part of the intertidal flat that has not been nourished (114 vs. 18 times in 4 days in two circles around the pole, Figure 4.9) (De Mesel and Ysebaert, 2009). This is not surprising given that the supply of food on the nourished area is still restricted in contrast with the rest of the intertidal flat. This is naturally an initial trial test and in order to report more confidently about the occurrence of birds, more surveys and a correction for the surface area are necessary.

Identification of the species was generally possible at a distance of circa 100 meters with a zoom factor of 7700 (9999 is the maximum; therefore it could still be magnified slightly more). Some species are easier to distinguish from their environment and to identify than others.

Coverage of the nourishment by macroalgae

Very little is known about the importance of macroalgae to the Galgeplaat. However there are a number of hypotheses in which the macroalgae cover plays a role:

- Large quantities of (non-native) algae can reduce the available foragable area for birds;
- Macroalgae that are fixed in place (for example, on oysters) can be interesting for different types of birds because there are different types of small animals in it;
- The decomposition of macroalgae can lead to anoxic conditions;
- Macroalgae can hold water and trap sediment.

The macroalgae cover is very simple to derive automatically from the image using a ‘k-means’ algorithm. The algorithm clusters pixels into a number of groups with similar colour values. In this case one group of colour values is representative for macroalgae, and a second group for other colour values. This produces a picture of the macroalgae cover.

However, a small layer of water, small waves or reflections on the wet surface can cause problems. Also it can be difficult to distinguish macroalgae from other (dark) clusters such as clumps of oysters. Nevertheless, such oyster clumps are in general very small in relation to the surface of the macroalgae which means the resulting deviation is relatively small.

In this trial test the macroalgae cover is measured at a location on the Galgeplaat outside the nourishment area in the northwest of the ARGUS-BIO station, over a period at the end of the summer. In this period there are often lots of macroalgae present. Various photographs were taken and the macroalgae cover is clustered (Figure 4.12). The percentage of cover is given in Figure 4.13.

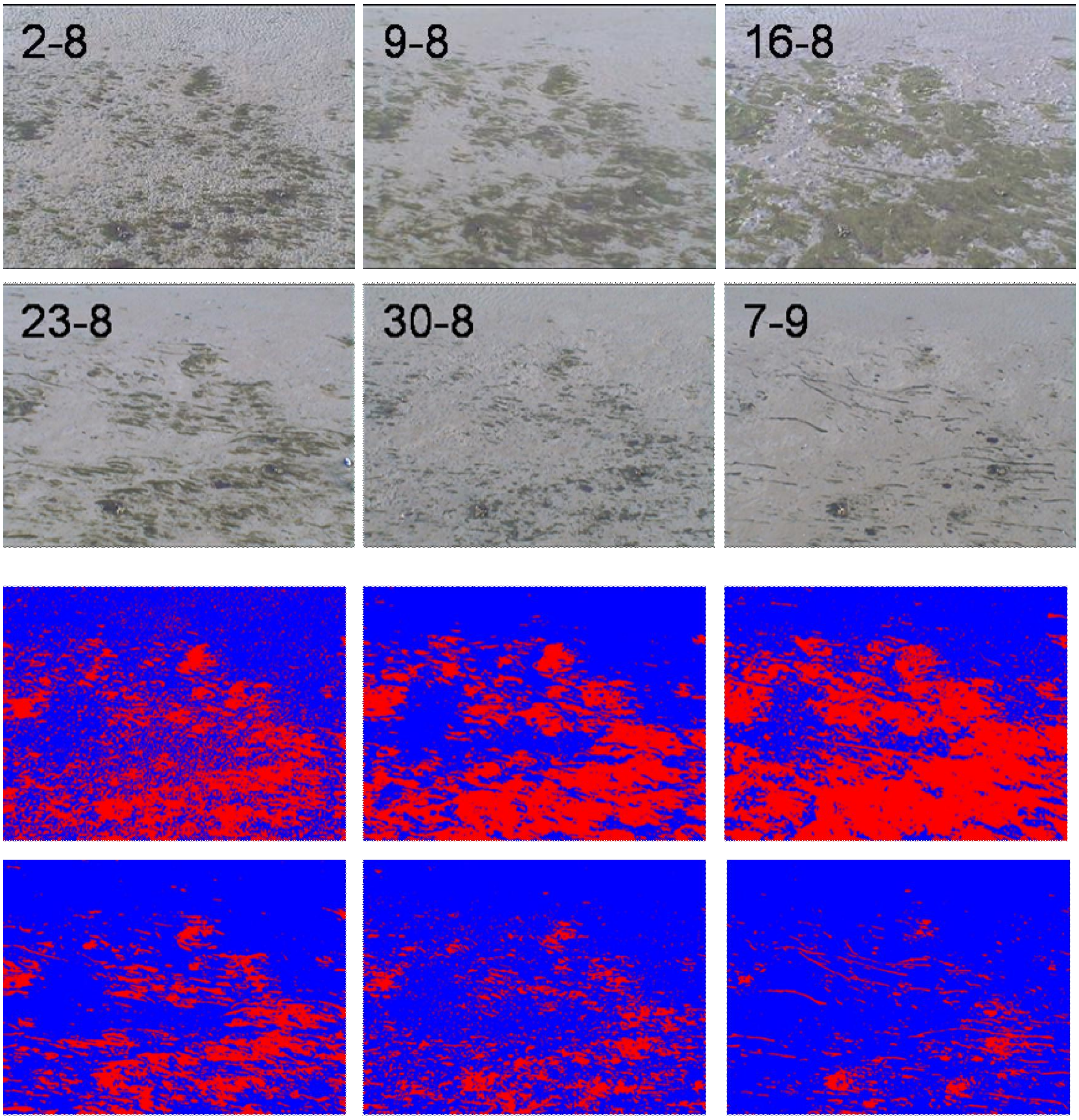


Figure 4.12 Cover by macroalgae in August-September 2009. Top: normal photographs, below: clustering of macroalgae (red) and other (blue)

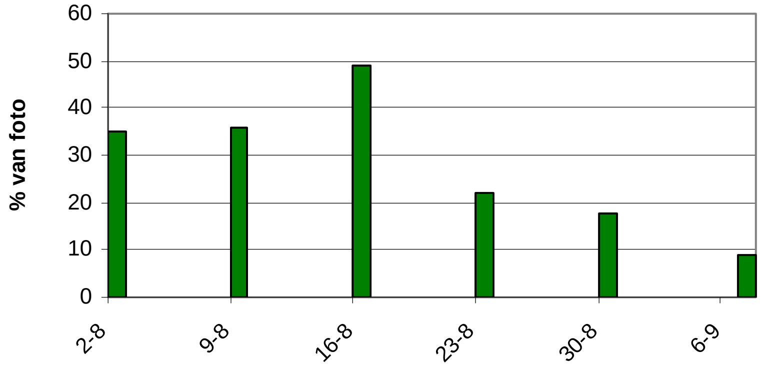


Figure 4.13 Percentage of cover for a location on the Galgeplaat over the period August-September 2009

The photographs as well as the calculated percentages show a clear trend. Up until half way through August the quantity of macroalgae increases and thereafter declines.

4.4 Observation of the biogeomorphological processes and interactions

On the Galgeplaat a large range of biogeomorphological processes are taking place that are not yet all understood. The ARGUS-BIO station is very valuable if only for the increase in the biogeomorphological knowledge: it can record biological as well as geomorphological parameters with a high resolution in time and space. Hypotheses have been formulated in various frameworks, which relate to bed level, sediment composition and bed roughness in combination with the presence of biota. A few methods to follow biogeomorphological developments are given here and coupled to the question: is the nourishment achieving its ecological objective?

4.4.1 Wet areas and sediment composition

Charting the wet areas of the nourishment is interesting because these areas very probably have a different benthic fauna than the higher and drier parts of the nourishment. In addition wet areas will probably develop in a morphologically different way to the drier areas. The hypothesis is that a nourishment with pools and small tidal creeks is more ecologically valuable than a flat nourishment with steep edges, but this has not yet been quantified.

Birds forage along the receding shoreline during the ebb tide. At the moment the birds are infrequently searching for food on the nourished area. A possible cause is that the edge of the nourishment is too steep which means that the shoreline does not move sufficiently slowly during the ebb tide. Wet, slow-drying areas on the nourishment could be more attractive to birds than the edge of the nourishment, provided there is sufficient benthic fauna. Sediment composition will also play a role in this. A large part of the nourishment is sandy, but the presence of the stagnant water in the pools gives fine sediment the opportunity to sink. These areas could slowly become siltier, and therefore will drain even more slowly. Silt-rich beds often house more and different organisms than sandy beds. However, in the Eastern Scheldt there is very little silt present, so this effect will be minimal.

In quiet hydrodynamic circumstances benthic fauna present will be able to influence the sediment composition; for example, by stirring the top layer of the sediment. The causes and consequences of this are difficult to separate from each other.

Monitoring the wet areas of the nourishment over a tidal period and over the course of the year, combined with the numbers of birds present that remain in the area, gives an indication of whether the wet areas are valuable or not. Monitoring the contours of wet areas over the tidal period is possible with the pictures taken by the four fixed cameras (see Figure 4.14). The automatic shoreline-recognition algorithm is not yet completely suitable for these small, often misshapen areas. Therefore it is still very manual and intensive work to map the wet areas of the nourishment at this point in time.

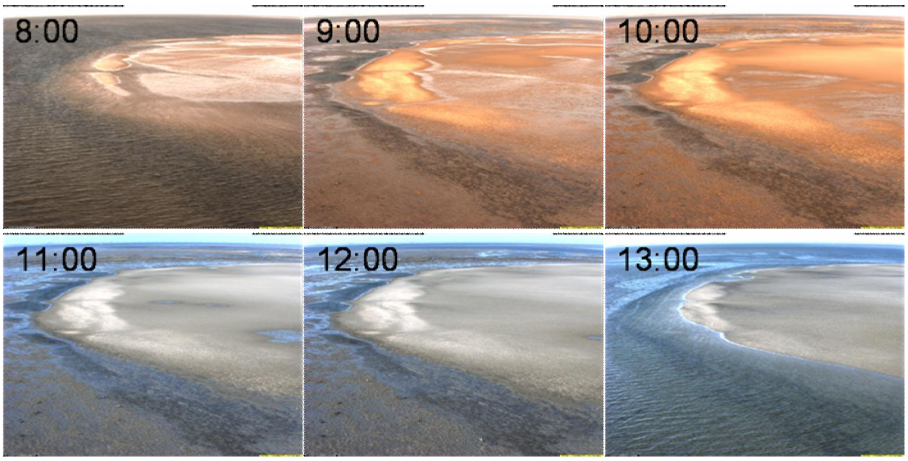


Figure 4.14 The emerging and inundating of the western part of the nourishment on 15 March 2009. In the course of the tidal period the areas which are high, dry or stay longer wet can be clearly seen

4.4.2 Bed roughness

The hydraulic roughness of the bed is important for currents, wave damping and sediment transport. This roughness is in turn determined by the currents, waves and the bed sediment present via bed forms such as ripples and ridges, but also by biota. Three examples of biota which the currents, waves and sediment transport can influence are obstacles such as oyster beds; small protruding siphons from filter feeders; and the coverage of the bed with ‘diatom mats’ (see Figure 4.15). The morphological development of the nourishment in the coming years will thus be partly determined by the biota present.

Figure 4.15 Various bed forms and other roughness-determining factors. From left to right: sand partly covered with diatoms; sand with ridges; mudflat with oyster beds

The bed roughness plays an important role in hydraulic models. Models can be used to predict the development of measures such as this nourishment globally. When the biota significantly influences the bed roughness, it must be coupled back to the hydraulic models. In this way it is possible to optimize any possible future measures using ecology. Research has shown that it is possible to include the influence of benthic fauna on sediment transport in models (Borsje et al., 2008). A good picture of the spatial pattern and the development in the tide of the benthic fauna present is essential for this. This information can only be obtained by almost constant measurement of the presence and spread of the benthic fauna. Here the ARGUS-BIO station offers a solution. By constantly monitoring the morphological and biological developments in combination with hydrodynamic data, a unique dataset emerges that can contribute to the knowledge of these biogeomorphological processes and the further development of similar models.

Many roughness-influencing bed features and benthic fauna are reasonably easy to find if they are close to the ARGUS-BIO station (up to roughly 200 meters from the pole). However, although structures are identifiable, quantifying them (for example, size of an oyster bed, the number of sandworms per square meter, ridge height) is often still difficult and requires a lot of time, because there are not yet any automatic recognition algorithms available.

4.4.3 Diatoms

Diatoms behave differently to macroalgae and also have a different effect on their surroundings. The most important functions of diatoms are:

- Bed stabilisation through the secretion of sticky extracellular polysaccharides (EPS)
- Food for benthic fauna.

The occurrence of diatoms depends on the sediment composition, dynamics and the availability of nutrients. The seasonal dynamics of diatoms are clearly different to those of the macroalgae. In short, diatoms grow explosively at the start of the spring whilst there is sufficient light available. Thus a lot of nutrients are taken in, which are therefore no longer available for the growth of macroalgae which is therefore delayed. In the summer period the grazing pressure by, for example, benthic fauna is higher, which results in fewer diatoms. At the end of the summer the grazing pressure slows down, resulting in more diatoms. From year to year this seasonal dynamic changes, depending on external factors such as the weather. It is valuable to record the quantity of macroalgae and diatoms during the year in order to understand the seasonal dynamics of diatoms and macroalgae better, as well as the nutrient content and the bed-stabilizing effect.

Just as with macroalgae, diatoms are easy to recognise with the naked eye if they occur in large quantities (see Figure 4.16). However in photographs they are less obvious against other brown objects. In addition they can be hidden in the sediment, making them invisible, especially when there is a small layer of water. A multispectral camera, with light sensors as well as sensors for certain frequencies of infrared light, makes it easier to distinguish diatoms from their surroundings. Chlorophyll c which is specific to diatoms gives a very characteristic signal which is different to the chlorophyll detected in macroalgae (Méléder et al., 2003).

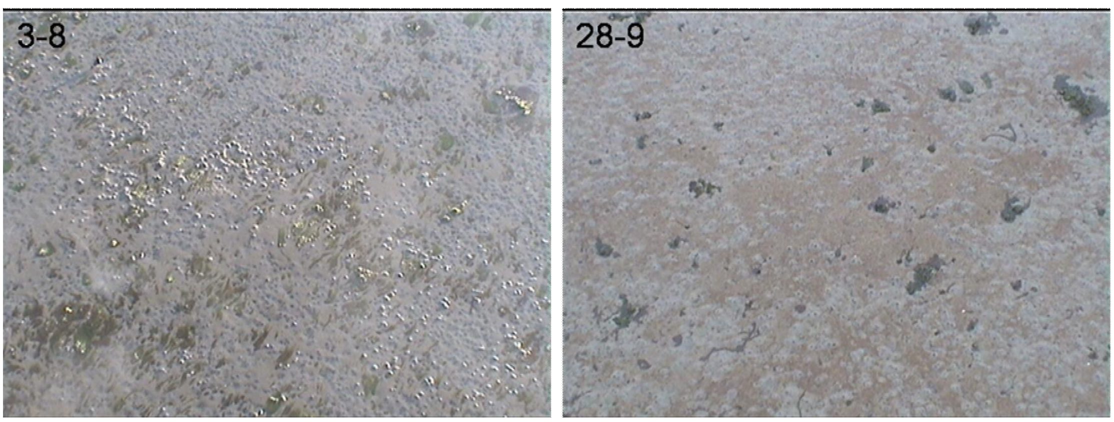


Figure 4.16 Dynamics in diatoms: photographs taken by the ARGUS-BIO camera (P/T/Z 225/45/3700) on 3 August and 28 September 2009. Both photographs show yellowy-brown areas, covered with various quantities of diatoms. To what extent this visible difference is representative of a difference in biomass or in visibility is not yet known.

4.5 The future: new measuring methods and apparatus

The ARGUS-BIO station has been running for a year now. After various tests and the first global analyses of the pictures it would appear to be a good idea to carry out a number of changes so that the data can be analysed better. This partly concerns the method in which pictures are taken, and partly the apparatus.

From the first analyses it appears that it is important to establish the periods of rising and falling water more accurately so that more shorelines can be mapped and as a result the bathymetry can be determined better. Very frequent images of the morphology give above all extra insight into the morphological processes that are taking place during storms. During quiet periods morphological processes occur much slowly and the high frequency of photographs is not necessary.

The ecological processes occur more quickly. Birds follow the shoreline during their foraging because most food can be found in the wet zone. With high frequency images this behaviour can be clearly observed. The identification of the birds remains difficult but short films of the behaviour of birds can make the identification easier.

As well as changes to the methods of collecting the data, the apparatus can also be improved. The identification of diatoms and macroalgae on the basis of colour can be very susceptible to errors. A multispectral camera which is set up to differentiate between the specific reflection of chlorophyll in near-infrared from the rest of the spectrum offers a possibility. Just as for the other parameters, a comparison with the field data is necessary for validation and to determine the reliability of the picture.

The identification of birds and sandworm casts requires a lot of detail and therefore an ARGUS-BIO camera with a higher resolution and a better zoom lens would make it possible to make more details visible in the first 200 meters around the platform.

Finally, photographs are only being taken at the moment when there is sufficient light. In order to see birds at night, infrared lights and electricity are required. Very little is known at the moment about the nocturnal behaviour of birds which makes the picture very one-sided. Images taken by Imares' camera on the Balgzand have shown that birds (oystercatchers) also forage at night.

Given that new apparatus, more pictures as well as higher resolution pictures would encumber the electricity provision as well as the data transfer, this might have to be adjusted. Extending the battery capacity is possible but in darker periods in winter it might not be enough and a fuel cell could be necessary.

5 Conclusions and recommendations

5.1 Conclusions and recommendations for the hydrodynamics and morphodynamics

The hydrodynamics are defined by the tide as well as by the wind. The dominant wind direction in the Marollegat was southwesterly. The majority of waves close to the Galgeplaat have a northwesterly or southeasterly orientation. This is possibly related to wave refraction as a result of the tidal current at the location of the Waverider, which is southeasterly-south-southeasterly during flood and approximately northeasterly during ebb. It could also be influenced by the fact that waves with a northwesterly or southeasterly orientation have a larger fetch in the Eastern Scheldt and therefore can propagate further. It is recommended that the differences in wind and wave direction are studied further.

The higher, northerly part of the nourishment (>+0.25 m NAP) has been eroding. At the end of December 2009 it had almost completely disappeared (0.1-0.2 m in the period concerned). In addition, there has clearly been sedimentation along the northeasterly edge of the nourishment. In the 15 months of the study, this movement has been in the order of 10-20 m and is most visible on the northeasterly edge.

There appears to be a seasonal effect in the sedimentation and erosion patterns. This is not in itself strange. A few measurements show that the biggest changes take place in the autumn and in the winter (September up to and including March), when there are generally higher wind speeds and therefore higher waves. In the spring and in the summer (April up to and including August) there is very little sedimentation or erosion.

The nourishment remains longer dry than the rest of the intertidal flat. The erosion of the higher parts of the nourishment is clearly shown in a reduction of the area that is dry at higher water levels. The area that remains dry at +0.25 m NAP increased in October 2008 to 2.3 hectares as a result of the nourishment, but in December 2009 there was almost no area left that is dry at this water level.

The nourishment has not yet ensured an increase in the duration of exposure around the nourishment. At present, the foraging time for birds has only improved at the nourishment itself.

The cubic volume of the nourishment shows a decrease of 1-2% of the nourished volume. This corresponds to an erosion of approximately 1-2 cm which corresponds to an erosion rate in the order of 1 cm per year. This concurs with the average rate at which the mudflats and intertidal flats are eroding in the Eastern Scheldt.

5.2 Conclusions and recommendations for the ecology

The number of birds on and around the nourishment is still very low. In addition, the birds are still not making use of the nourishment when foraging. The possible cause of this could be that there is still insufficient benthic fauna present on the nourishment. Benthic fauna samples show that a recovery is taking place but that the benthic fauna community is not yet at the level of 2007.

A possible cause of the low amount of benthic fauna is the sediment composition. The nourished sand had a larger grain size than what was originally present. Also it is not yet known whether the packing/density of the sediment also plays a role in addition to the grain size in the recovery of the benthic fauna on the area of nourishment.

There have been no negative effects from the dredging and nourishment activities on the growth and development of the mussels in the mussel beds nearby.

5.3 Conclusions and recommendations for monitoring

Various measurement methodologies have been applied in order to determine the bed level: RTK-DGPS profiles and grids, single beam measurements over 25 m and 50 m transects and Sedimentation erosion measurements (SET). The SET measurements, RTK-DGPS profiles and RTK-DGPS grids match but the single beam measurements diverge more. The single beam measurements give a synoptic image, but are not accurate enough to show small changes in the bed level (accuracy in the order of 0.1 m). The RTK-DGPS grids, profiles and SET measurements are very valuable for the analysis of the morphological development of the Galgeplaat.

It is important to allow the profiles to extend over the edge of the nourishment so that the movement of the nourishment can be tracked.

The RTK-DGPS measurements are restricted mainly to the original nourishment location. It is recommended that the RTK-DGPS measurements are extended in the direction where the nourishment is developing.

The bird surveys are only carried out on one or two days a year, giving a snapshot of the birds present at that time. As well as the bird surveys, details from other studies (for example, the ANT study) are useful in order to evaluate the effectiveness of the nourishment for the birds in the Eastern Scheldt. The ARGUS-BIO station is making continuous records of the presence of birds and on the basis of these pictures it could be possible to sketch a general picture of the use of the nourishment by birds.

The benthic fauna sampling is only carried out once a year (in 16 locations) so seasonal influences are difficult to ascertain. Data from other studies (for example, Building with Nature) are also important in order to get a more complete picture of the recovery of the benthic fauna on the Galgeplaat.

Some of the benthic sample locations were moved, added or removed in 2008 compared to the sample locations in 2007. This means that it is not possible to analyse all the sample locations in relation to 2007. It is thus recommended to keep the sample locations on the same sites over the coming period.

The ARGUS-BIO pictures show that various forms of benthic fauna (such as worms, macroalgae and mussels) can cover whole areas of the nourishment and that these areas vary during the course of the year in terms of size and location. It is recommended that these areas are periodically (for example, at the same time that the bed level is measured using the RTK-DGPS) mapped using a type of field mapping. These maps will contribute to the understanding of the biological processes on the Galgeplaat throughout the year. In addition it will contribute to the understanding of the interactive processes between the biological activity and the sediment transport which are taking place on the nourishment.

5.4 Conclusions and recommendations for the ARGUS-BIO station

Monitoring with the help of the ARGUS-BIO station makes it possible to constantly monitor the development of the bed level, without having to go to the Galgeplaat itself. The comparison of the ARGUS bed level map with the field data shows that both monitoring techniques produce comparable results.

The ARGUS-BIO station produces data with a high frequency. This has the advantage that the effect of a particular event (for example, a storm) can be immediately determined and compared with developments over the longer term.

The ARGUS-BIO camera offers the possibility to count birds on a daily basis without disturbing them. In addition, the coverage by oyster beds, macroalgae and diatoms can be determined. These parameters are not included in the normal monitoring programme but are of importance for the development of the nourishment.

At the moment the ARGUS-BIO station is an experimental system. In order to be able to maximize the potential of ARGUS-BIO station a number of improvements are necessary, such as the use of local water level data, regular calibration of camera positions, improved geometric solutions, and algorithms to recognize macroalgae, oyster beds and birds.

5.5 Conclusions on the effectiveness of the nourishment

The nourishment on the Galgeplaat was carried out to slow down the erosion of the intertidal flat in order to mitigate that fact that birds have insufficient time to forage. The nourishment can be seen as a sort of sand buffer from which the natural transport processes distribute the sand over the intertidal flat. In addition, the objective is for the nourishment to become part of the intertidal flat’s ecological system as quickly as possible. In this way the impact of the nourishment on the ecological system will be mitigated as much as possible.

The effectiveness of the nourishment is defined as the optimum between the ‘feeding’ of the surrounding intertidal flat and the time needed for the recolonisation of the nourishment by benthic fauna in relation to the time in which the exposure duration declines again as a consequence of the erosion of the nourishment. The developments are taking place slowly and a definite conclusion cannot be drawn yet but the interim impressions are positive:

- The nourishment has largely remained in its place during the last 15 months and has not been transported to the channel.
- The area surrounding the nourishment has not yet been supplied with sand.
- The recolonisation of the nourishment with benthic fauna is not yet at the level of 2007, but there are definite signs that the recovery has started.
- The exposure duration has increased at the nourishment location. In the last 15 months very little material from the nourishment has eroded so that the exposure duration has not yet noticeably reduced.

The time span for which data is now available is however still too short to be translated into a forecast of the development of the exposure duration, the development of the surrounding intertidal flat or the recovery of the benthic fauna. It is thus not yet possible to give an estimate of the optimal nourishment strategy.

Whether the effects will be sustainable on a larger spatial and/or temporal scale cannot only be determined based on the evaluation of the field data from this nourishment. Additional model calculations are needed in order to be able to accurately predict the morphological development. The knowledge obtained from this nourishment should be used for this.

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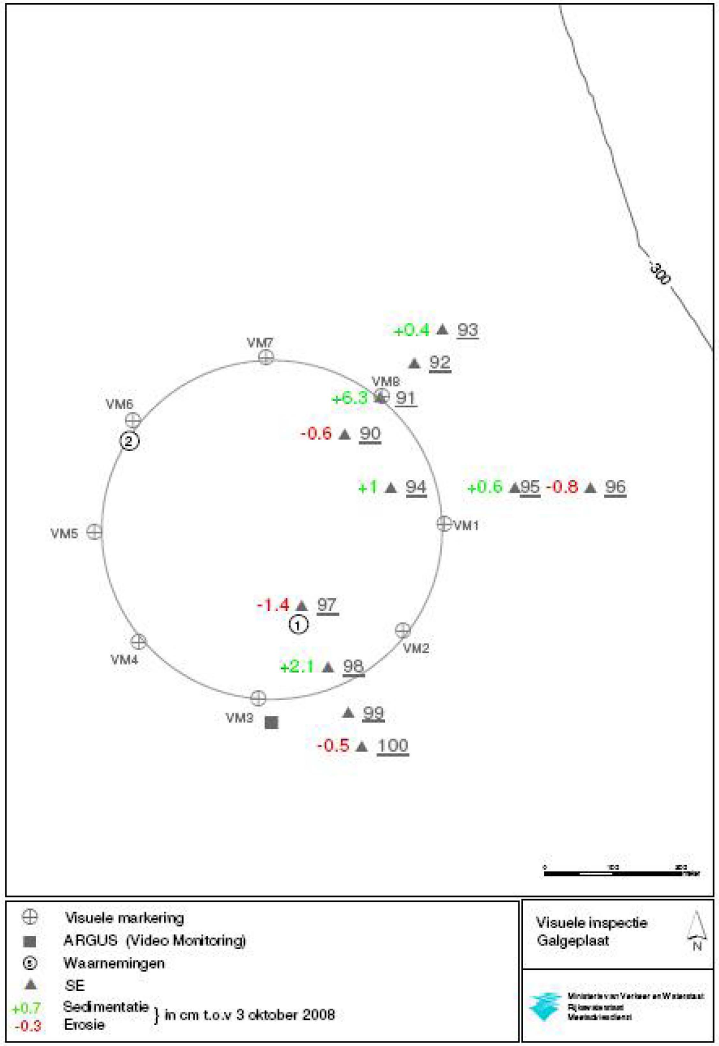
A Visual inspections



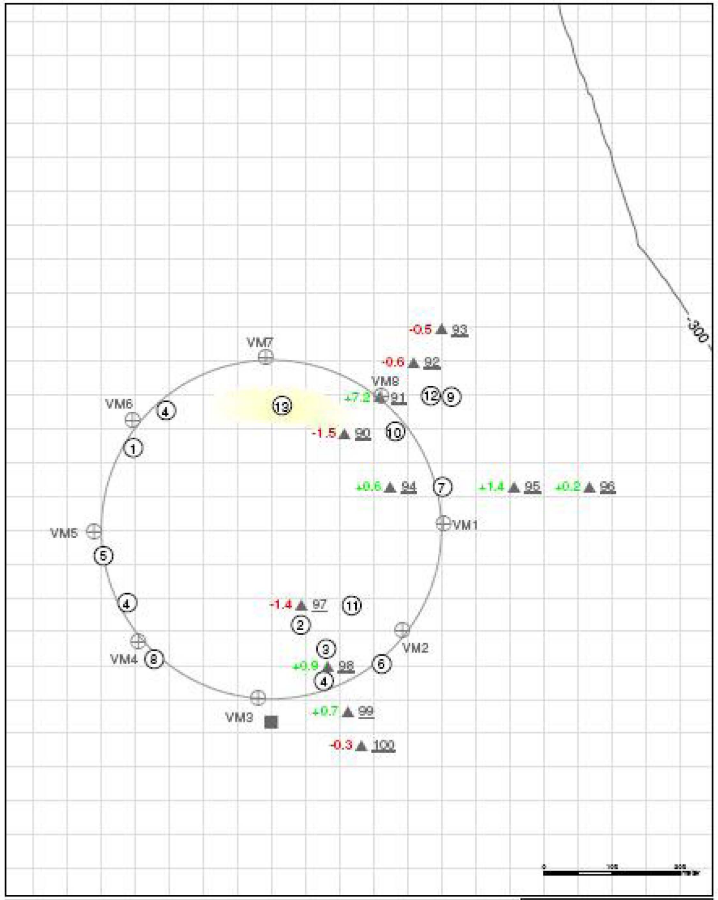
Visuele inspectie Galgeplaat

29 oktober 2008

Waarnemingen: E. Parée en M. Bijleveld

① Wadpieren

② Uittredend zuurstofloos water



- ⊕ Visuele markering
- ■ ARGUS (Video Monitoring)
- ⓔ Waarnemingen
- ▲ SE
- +0.7 Sedimentatie / -0.3 Erosie } in cm t.o.v 29 oktober 2008

Visuele inspectie Galgeplaat

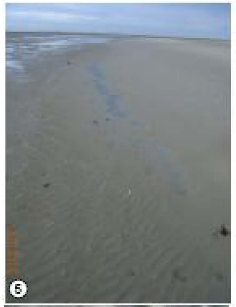
Ministerie van Verkeer en Waterstaat Rijkswaterstaat

Visuele inspectie Galgeplaat

26 november 2008

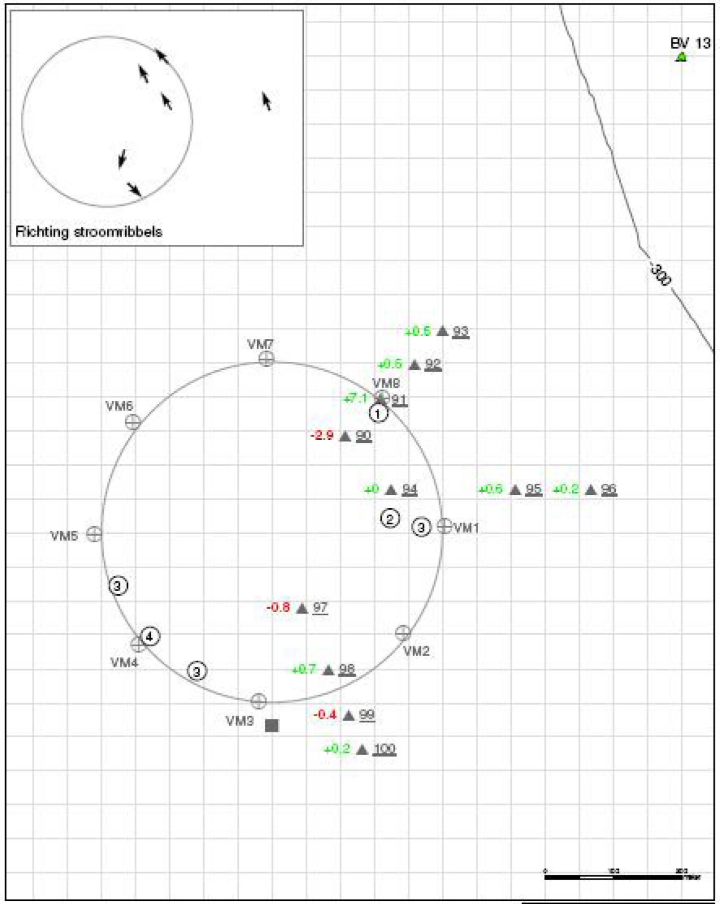
Waarnemingen: E. Parée en M. Bijleveld

1. Wadslakjes
2. Wadpieren
3. Wadpieren en vogelsporen
4. Bij opkomend tij groep van 500 scholeksters op rand van suppletie
5. Uittredend zuurstofloos water
6. Diatomeeën
7. Iets diatomeeën
8. 1m diepe put + stroomribbels
9. Stroomribbels
10. Mooie stroomribbels
11. Flauwe stroomribbels
12. Aanzanding punt 91
13. Gebied met plofzand







Visuele markering
ARGUS (Video Monitoring)
Waarnemingen
SE
+0.7 Sedimentatie
-0.3 Erosie } in cm t.o.v 26 november 2008

Visuele inspectie Galgeplaat

N

Ministerie van Verkeer en Waterstaat
Rijkswaterstaat
Meetadviesdienst

Visuele inspectie Galgeplaat

14 januari 2009

Waarnemingen: E. Parée en M. Bijleveld

Opvallend groot aantal vogels, maar voornamelijk net naast de suppletie. Een aantal, waaronder grote mantelmeeuwen en scholeksters, verbleven op de rand van de suppletie.

Op de suppletie zijn wederom vogelsporen aangetroffen, meer dan bij het bezoek van eind nov 2008.

Op 50% van de suppletie is de aanwezigheid van wadpieren waargenomen. Dat is minder dan tijdens het vorige bezoek. Aantallen variëren sterk van een enkel exemplaar tot tientallen per m2.

(1) De andere 50% van het suppletieoppervlak wordt gekenmerkt door de aanwezigheid van stroomribbels en weinig tot geen bodemleven.

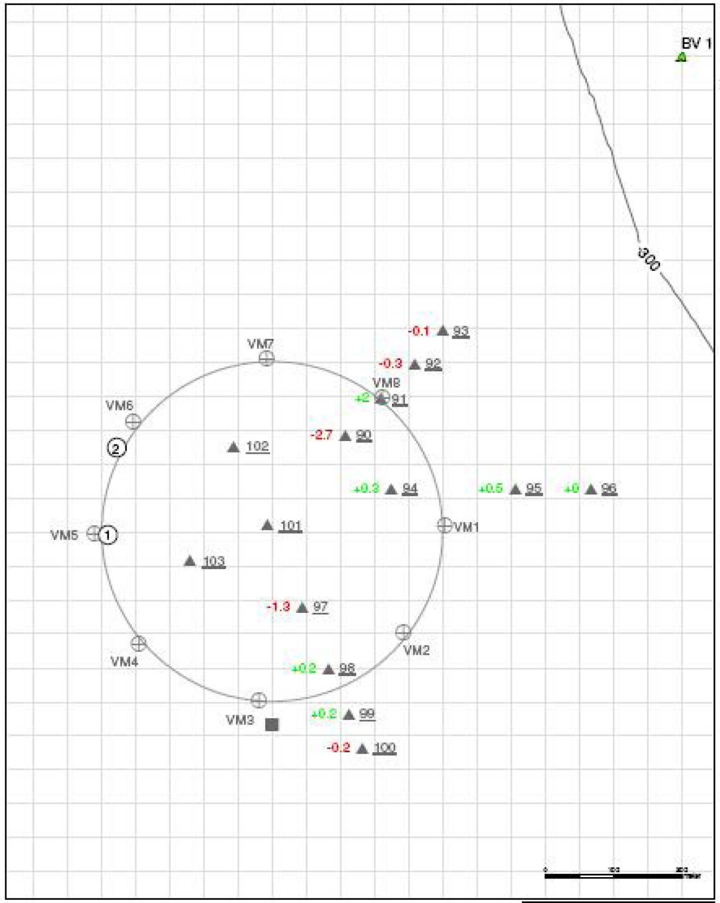
(2) Op het zand is op een aantal plaatsen een mooi lijnenspel aangetroffen. Als er bij afgaand water nog enkele cm's water aanwezig is en het golfribbelpatroon is reeds gevormd, maken grote meeuwen of ganzen deze wandelsporen.

(3) Aan de rand van de suppletie worden op diverse plekken schelpenruggen gevormd.
Foto schelpenrug tussen VM4-VM5

De diepte van de slijpgeul is stabiel.

De ARGUSpaal is nog niet voorzien van apparatuur.

(4) Afstand tussen VM4 en suppletierand wordt groter (zand verplaatst in oostelijke richting).



⊕	Visuele markering
■	ARGUS (Video Monitoring)
ⓢ	Waarnemingen
▲	SE
+0.7	Sedimentatie } in cm t.o.v 14 januari 2009
-0.3	Erosie

Visuele inspectie Galgeplaat

Ministerie van Verkeer en Waterstaat
Rijkswaterstaat
Meetadviesdienst

Visuele inspectie Galgeplaat

11 februari 2009

Waarnemingen: E. Parée en M. Bijleveld

Gasten: Gemma Ramaekers, Zheng Wang en Bas (Deltares)
Rienk Geene (Habitat Advies)
Piebe Hoeksma en Robert Jentink (DZL)

① Zandverplaatsing is duidelijk te zien bij VM5. Zand verplaatst in westelijke richting.

Wat opviel was dat er, in tegenstelling tot de voorgaande keren, over de gehele suppletie stroomribbels te zien waren. Dit is veroorzaakt door de giertijen van februari. In de Oosterschelde was het getijverschil dezer dagen bijna 4 meter.

② Op de rand van de suppletie fourageerden Kanoeten

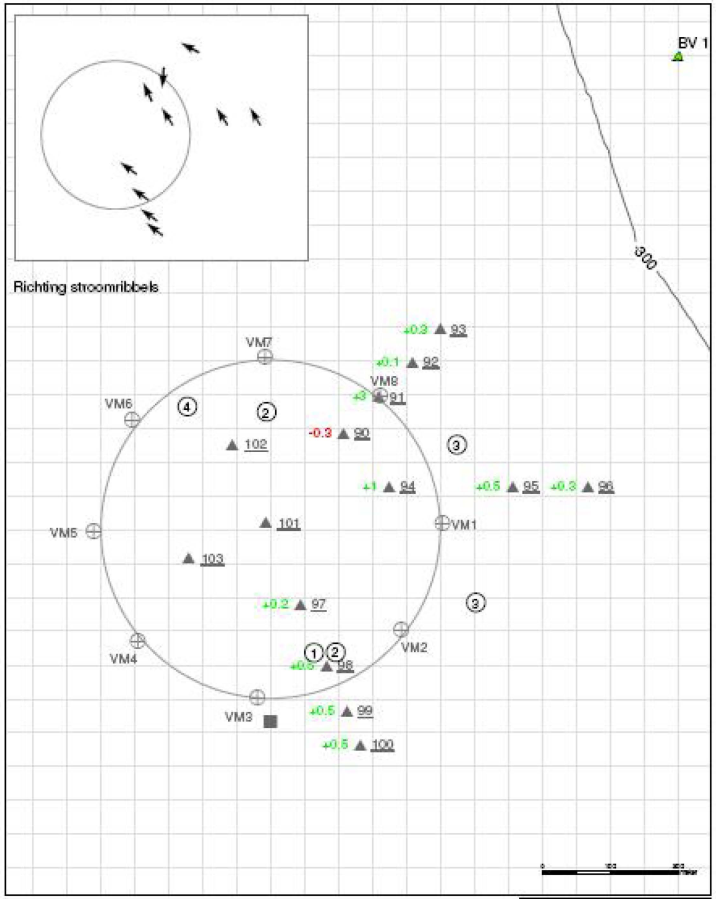
③ De ARGUSpaal is voorzien van apparatuur.

Er zijn 3 nieuwe sedimentatie/erosie (SE) meetpunten geplaatst.

Van de schelpenruggen die gevormd werden op de rand van de suppletie zijn slecht fragmenten terug te vinden. De schelpen liggen verspreid of zijn weggespoeld.

Er zijn nog steeds delen van de suppletie waar geen wadpieren voorkomen.

Een fotoverslag van Gemma Ramaekers van het bezoek is te vinden op
http://picasaweb.google.nl/gemmaramaekers/GalgeplaatFebruari2009#



⊕ Visuele markering
■ ARGUS (Video Monitoring)
⊙ Waarnemingen
▲ SE
+0.7 Sedimentatie, -0.3 Erosie } in cm t.o.v 11 februari 2009

Visuele inspectie Galgeplaat

Ministerie van Verkeer en Waterstaat, Rijkswaterstaat, Meetdienst

Visuele inspectie Galgeplaat

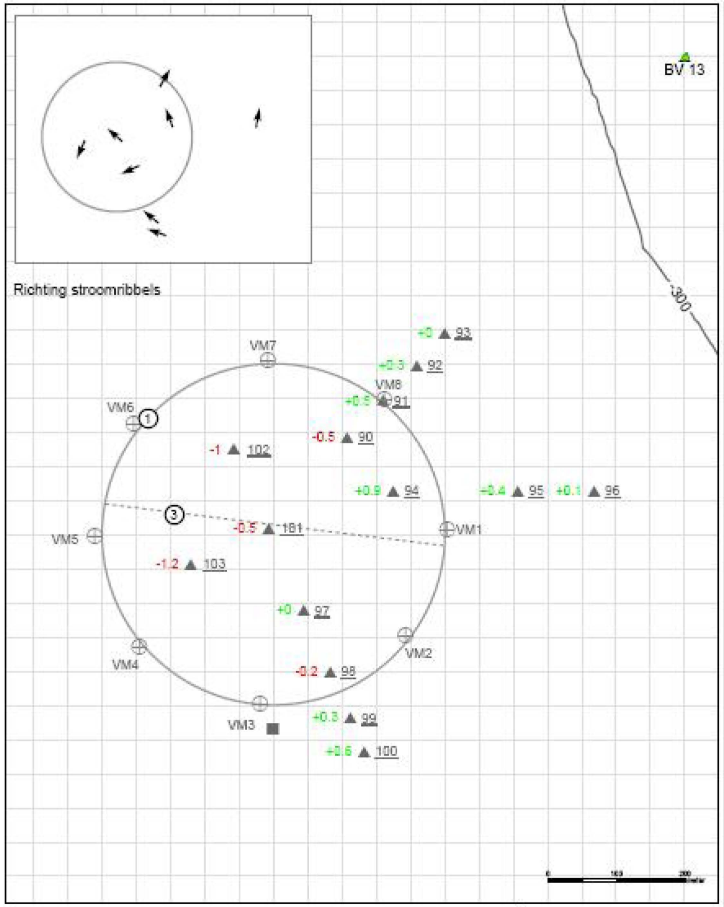
11 maart 2009

Waarnemingen: E. Parée en M. Bijleveld

Gast: Irv Elshoff (Deltares)

1. Begin diatomeeënbloei omgeving punt 98
2. Wadslakjes
3. Eikapsels van de Gestippelde Dieseltreinworm (3a) en de Wapenworm (3b)
4. Verspreid voorkomen van Tapijtschelpen

Verder weinig veranderingen ten opzichte van het vorige bezoek



⊕	Visuele markering
■	ARGUS (Video Monitoring)
⑤	Waarnemingen
▲	SE
+0.7 / -0.3	Sedimentatie / Erosie } in cm t.o.v 11 maart 2009

Visuele inspectie Galgeplaat

N

Ministerie van Verkeer en Waterstaat
Rijkswaterstaat
Meetadviesdienst

Visuele inspectie Galgeplaat

1 april 2009

Waarnemingen: E. Parée en M. Bijleveld

Gasten: Sletse en Mindert (Deltares)
6 mensen NIOO

① De grens van de suppletie is minder scherp zichtbaar in het landschap. Op de helling is rond de gehele suppletie bodemleven waargenomen in de vorm van wadpieren, kokerwormen, wieren en diatomeeën.
De helling lijkt wat slibrijker te worden. Met een geschatte hellingshoek van 1:15 wordt de suppletierand flauwer.
Op de foto's de suppletierand nabij VM6 en twee detailopnamen van het bodemleven op de helling.

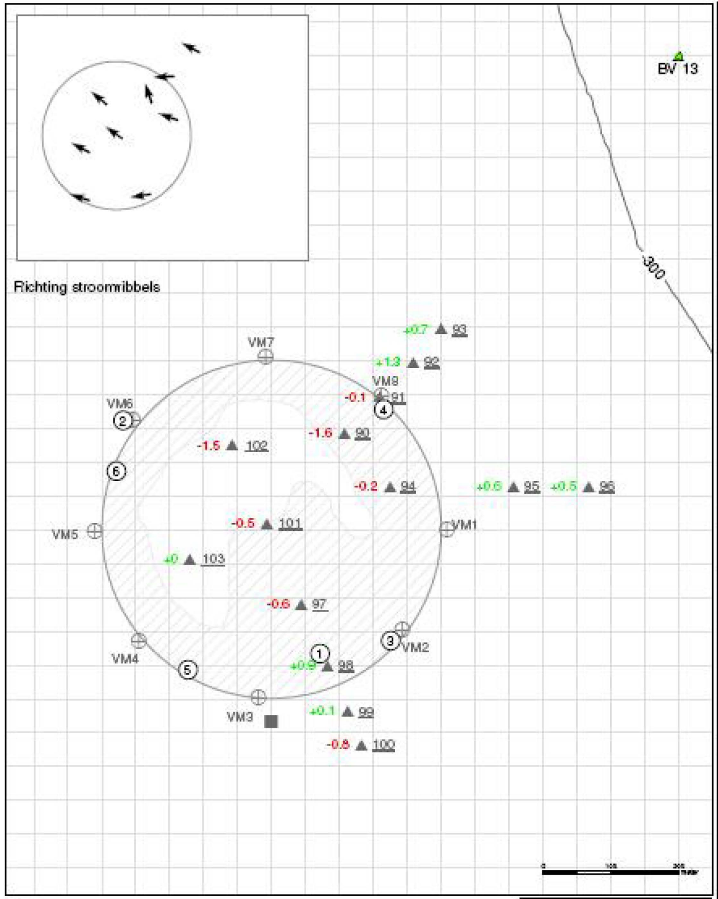
② Foto punt 103 toont forse stroomribbels, verzoorzaakt door hoge dynamiek.

Aan de noordkant komen op de suppletie regelmatig tapijtschelpen voor.

Rondom punt 102 plofzand

③ Ten zuiden van de stippellijn komen vrijwel overal diatomeeën voor.

VM1 12m zuidwaarts verplaats. Punt lag te dicht op meetraai (regelmatig omver gevaren)



- ⊕ Visuele markering
- ■ ARGUS (Video Monitoring)
- ⓢ Waarnemingen
- ▲ SE
- +0.7 Sedimentatie, -0.3 Erosie } in cm t.o.v 1 april 2009

Visuele inspectie Galgeplaat

Ministerie van Verkeer en Waterstaat
Rijkswaterstaat
Meetadviesdienst

Visuele inspectie Galgeplaat

13 mei 2009

Waarnemingen: E. Parée en M. Bijleveld

Gasten: Irv, Sytze en Mindert (Deltares)
Ronald Oostinga (DZL)

70% van de suppletie is gekoloniseerd door wadpieren (gearceerd in de afbeelding). De dichtheid varieert sterk: van 30 tot 800 exemplaren per m2. Op de suppletie zitten kleine wadpieren, alleen rond plot 97 zitten wat grotere exemplaren. Op de uitloop (sedimentatiezone) van de suppletie is de dichtheid van de wadpieren groter en komen er, naast vele kleine, ook grotere exemplaren voor. In het gebied rondom de suppletie, wat niet beinvloed is door sedimentatie, was lokaal ook een sterke toename van grote wadpierenhoopjes te zien.

Tussen de wadpieren zijn ook regelmatig kokerwormen en wadslakjes waargenomen.

(3) Over de gehele suppletie komen verspreid plukjes wier voor, waaronder draad- en darmwier.
Tussen VM2-VM5 komen de plukjes in grotere aantallen voor.

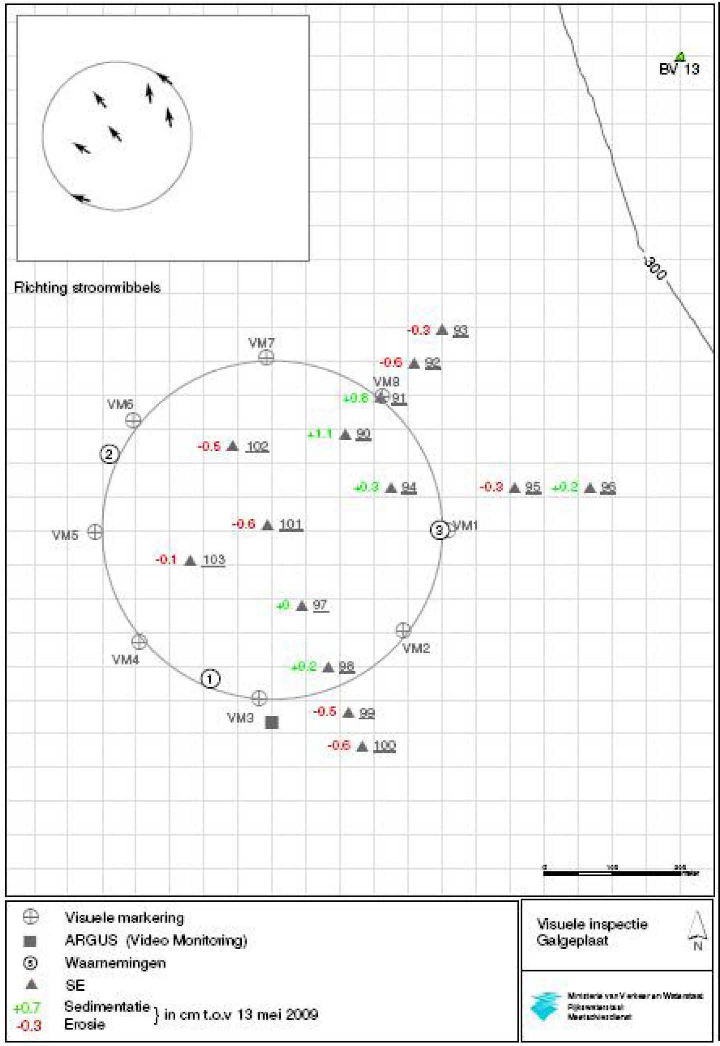
(5) 8 mosselen waargenomen. Deze zaten voor 2/3 ingegraven in het zand.

(6) Verspreid voorkomen levende kokkels.

Rond plot 102 plofzand

Slijpgeul is stabiel.

Tussen plot 101 en 102 grotere stroomribbels



Visuele inspectie Galgeplaat

10 juni 2009

Waarnemingen: E. Parée en M. Bijleveld

Gasten: Tom Ysebaert, (NIOO), Leo Zwarts (Altenburg en Wiebenga) Eric van Zanten, Dick de Jong, Dirk van Maldegem (DZL)

Het verspreidingsgebied van de wadpieren is gelijk aan vorig bezoek. De aantallen variëren sterk, van 32 m2 bij punt 103, tot 720m2 bij punt 98.

Gammarus waargenomen bij punt 91, 94 en 100

Het zand is nu in de zomermaanden een stuk minder in beweging. Dat er nog wel enig transport is laat foto 2 zien. Hier ligt vers zand bovenop het talud welke eerder met de ebstroom is meegenomen en tot hier (grens licht/donker) is neergelegd.

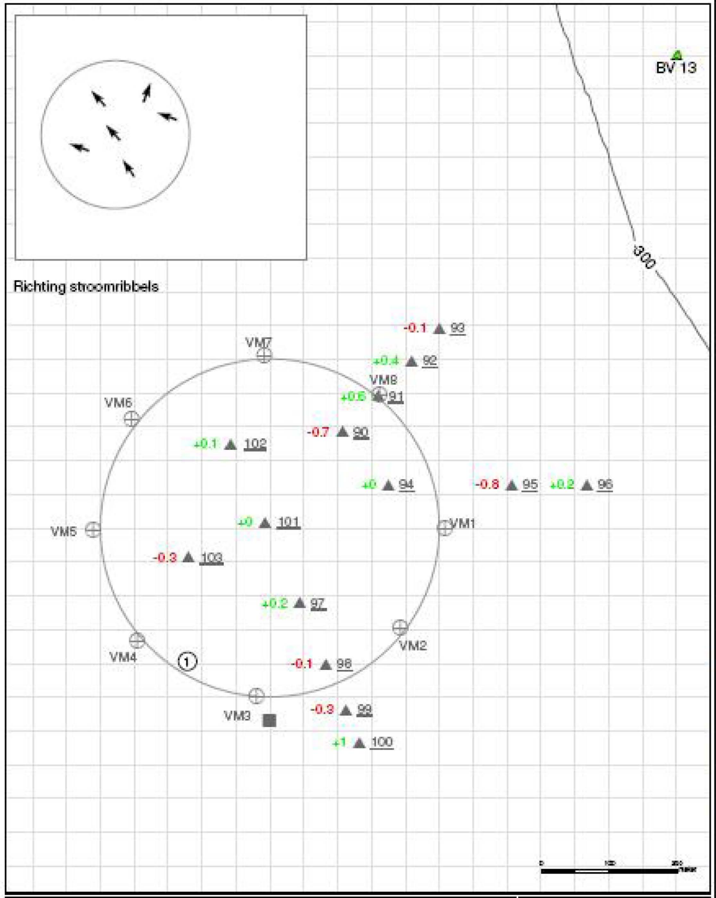
(1) De rand van de suppletie is overal bedekt met plukken wier. Tussen VM2 en VM5 ligt de bedekkingsgraad van het wier aanzienlijk hoger.

(3) Bij VM1 liggen in de sedimentatiezone Japanse Oesterbanken waarop zand wordt ingevangen.


1


2


3



Visuele markering
ARGUS (Video Monitoring)
Waarnemingen
SE
+0.7 Sedimentatie
-0.3 Erosie } in cm t.o.v 13 juni 2009

Visuele inspectie Galgeplaat

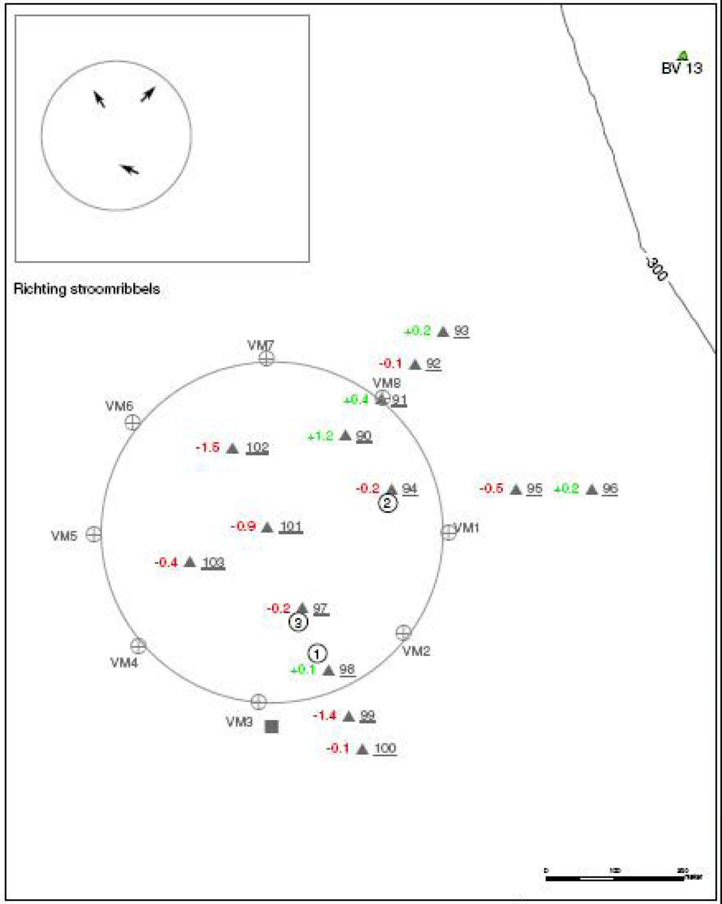
Visuele inspectie Galgeplaat

22 juli 2009

Waarnemingen: E. Parée en M. Bijleveld

Gasten: 3 (NIOO)

① Tussen vm3 en vm4 vormt zich zo'n 25 m van de suppletierand een lage zandrug.



Visuele markering
ARGUS (Video Monitoring)
Waarnemingen
SE
+0.7 Sedimentatie } in cm t.o.v 22 juli 2009
-0.3 Erosie

Visuele inspectie Galgeplaat

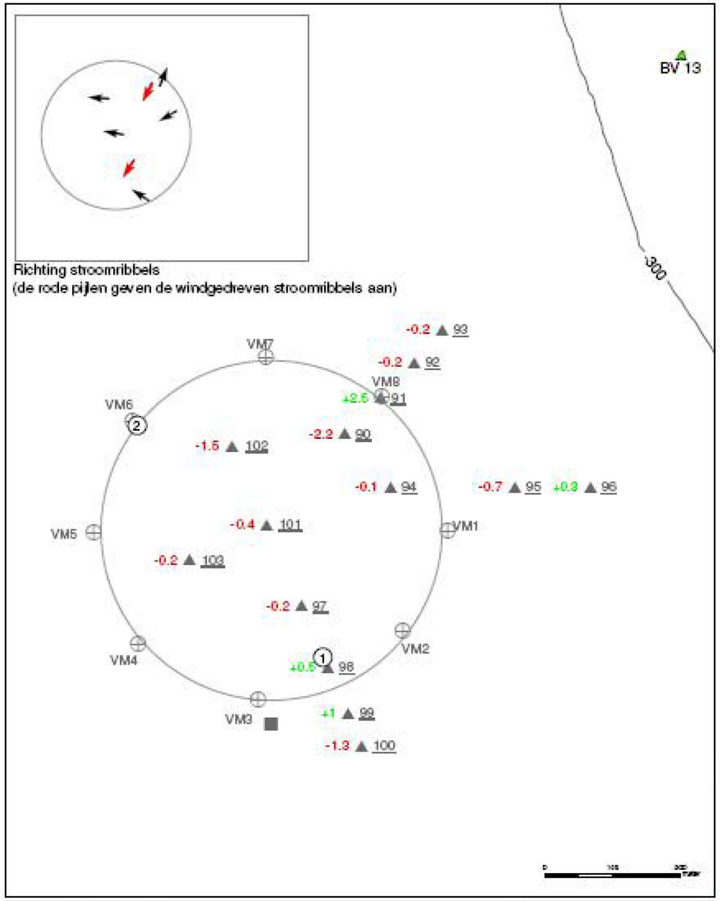
Visuele inspectie Galgeplaat

12 augustus 2009

Waarnemingen: E. Parée en M. Bijleveld

① Rondom de punten 97/98 toont de bodem het karakteristieke "wadpieren profiel".

② ③ Bij punt 94 en punt 97 is actief gezocht naar schelpdierbroed (zoekgebied 1m2). Bij punt 94 zijn 2 juveniele kokkels gevonden . Bij punt 97 waren er meer jonge schelpdieren: 8 kokkels en 1 tapijtschelp.



⊕ Visuele markering
■ ARGUS (Video Monitoring)
ⓢ Waarnemingen
▲ SE
+0.7 Sedimentatie
-0.3 Erosie } in cm t.o.v 12 augustus 2009

Visuele inspectie Galgeplaat

N

Visuele inspectie Galgeplaat

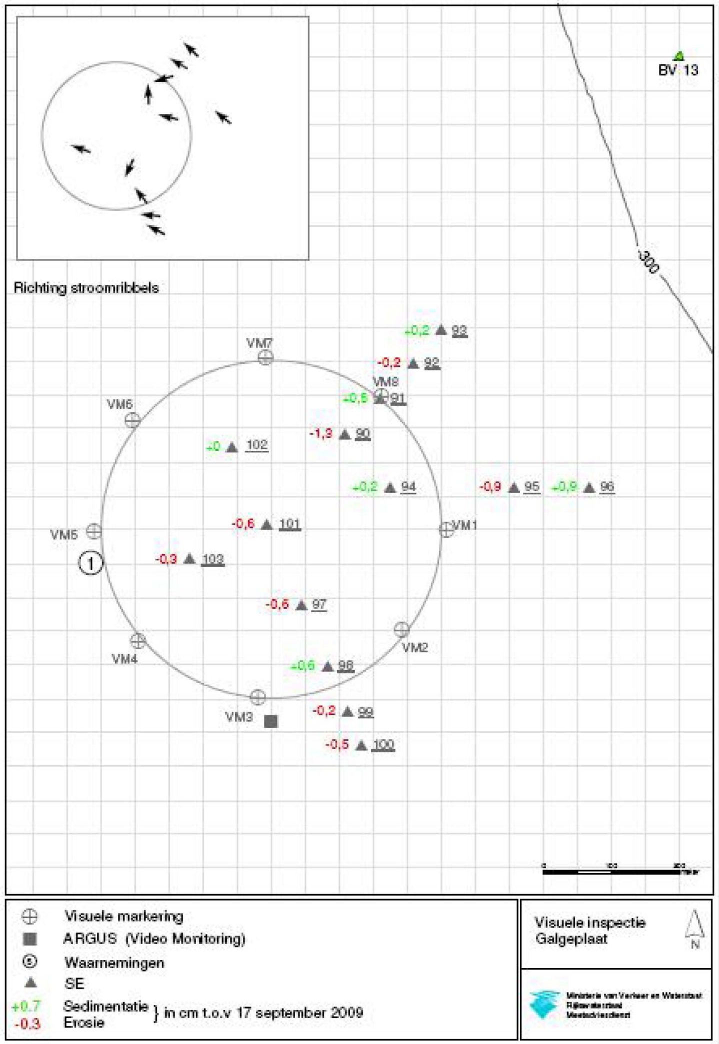
17 september 2009

Waarnemingen: E. Parée en M. Bijleveld

(1) Jonge schelpdieren bij punt 98 (1 m2). Bij punt 103 zijn 3 volwassen kokkels, 1 juveniel en 2 mossels aangetroffen.

De grens waar de wadpieren voorkomen in het midden van de suppletie schuift op naar het noorden. Tot enkele meters na punt 102 komen er (kleine) wadpieren voor. De aantallen zijn laag (4 m2).

(2) Op de rand van de suppletie tussen VM5 en VM6 zijn grote stroomribbels te zien veroorzaakt door de vloedstroom.



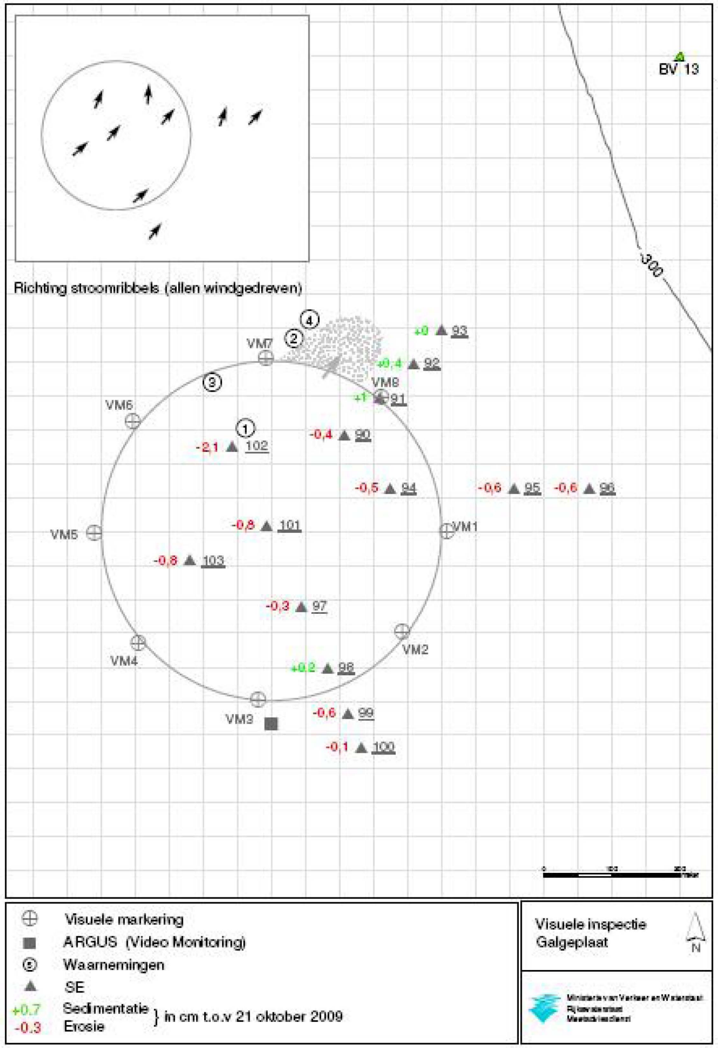
Visuele inspectie Galgeplaat

21 oktober 2009

Waarnemingen: E. Parée en M. Bijleveld

(1) Bij de afwatering van de suppletie vindt zandtransport plaats. Op de foto (rand en uitloop suppletie) bij VM5 is dit goed te zien. Het transport op dit punt is in westelijke richting. Op de dag zelf en de dagen voor de inspectie heeft er een stevige oostenwind gestaan. Vermoedelijk is dit zandtransport in westelijke richting ontstaan door de (oostelijke) windgedreven stroming.

De hoogte van alle topbuizen van de Sedimentatie/Erosie plotjes zijn opnieuw ingemeten, en de plotjes zijn ook weer vastgelegd op foto.



Visuele inspectie Galgeplaat

18 november 2009

Waarnemingen: E. Parée en M. Bijleveld

Gasten: Jan de Bel (DZL), 4 * Deltares

Inspectie met een stormachtige zuidwesten wind kracht 8. Rond laagwater kwam eolisch zandtransport op de suppletie op gang ten noorden van de lijn VM4-VM8. Foto 2 toont wier op 30m buiten de suppletie bedekt met een laag zand. Foto 4, op 50m afstand van de suppletie genomen, is duidelijk het neergeslagen zand te zien. P:\Suppletie Galgeplaat\fotos\divers\2009-11-18_Eolisch zandtransport.avi geeft een beeld van het zandtransport.

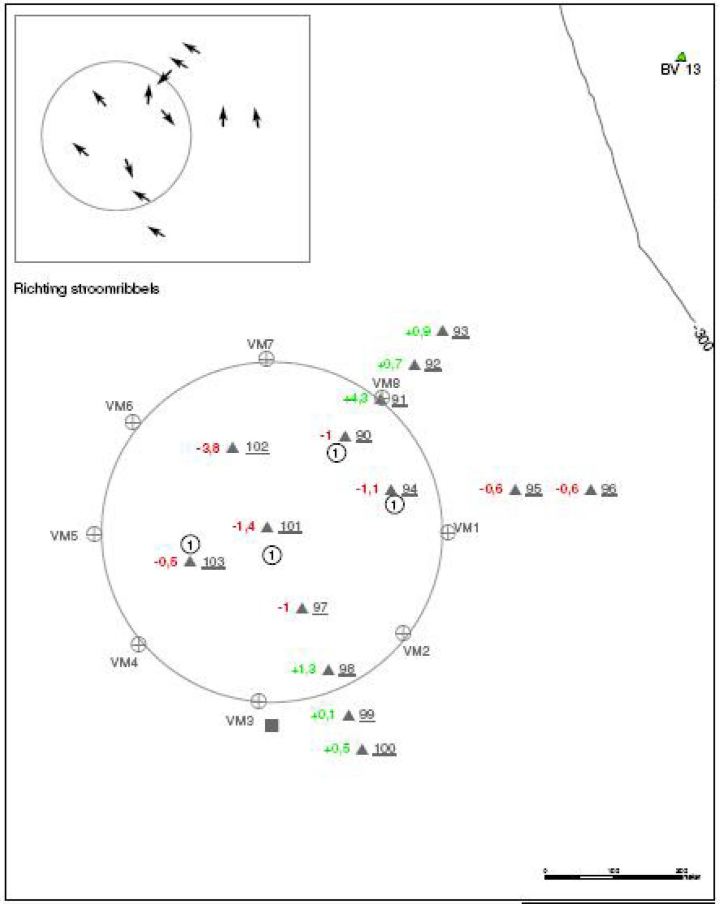
(1) Nieuw soort (zandtransport)ribbels waargenomen, op plaatsen waar meestal normale stroomribbels te zien waren, waren nu vormen te zien zoals op foto 1. Waarschijnlijk gevormd op moment dat er nog een klein laagje water op stond met flinke wind erover heen.

Kleine stukjes van de stortrand van de suppletie zijn zichtbaar geworden tussen VM4 en VM5.

Visuele inspectie Galgeplaat

16 december 2009

Waarnemingen: E. Parée en M. Bijleveld



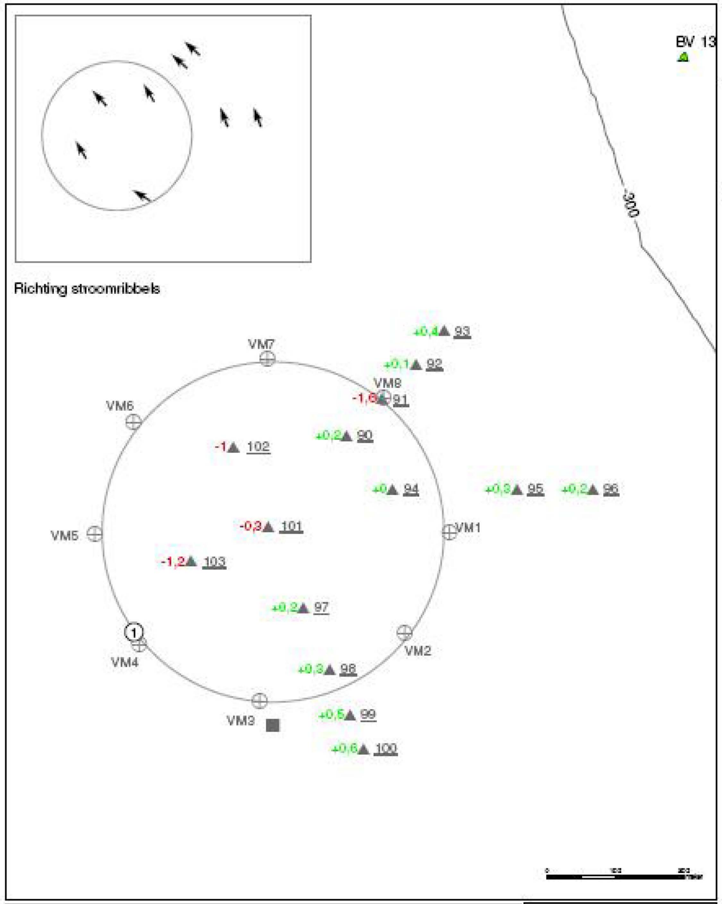
(1) Verspreidt over de suppletie kwamen op een aantal locaties grote aantallen wormen voor (Schelpkokerwormen ?)

⊕	Visuele markering
■	ARGUS (Video Monitoring)
(1)	Waarnemingen
▲	SE
+0.7 / -0.3	Sedimentatie / Erosie } in cm t.o.v 18 november 2009

Visuele inspectie Galgeplaat

N

Ministerie van Verkeer en Waterstaat
Rijkswaterstaat
Meetadviesdienst



⊕	Visuele markering
■	ARGUS (Video Monitoring)
ⓒ	Waarnemingen
▲	SE
+0.7 / -0.3	Sedimentatie / Erosie } in cm t.o.v 16 december 2009

Visuele inspectie Galgeplaat

Ministerie van Verkeer en Waterstaat
Rijkswaterstaat
Meetadviesdienst

Visuele inspectie Galgeplaat

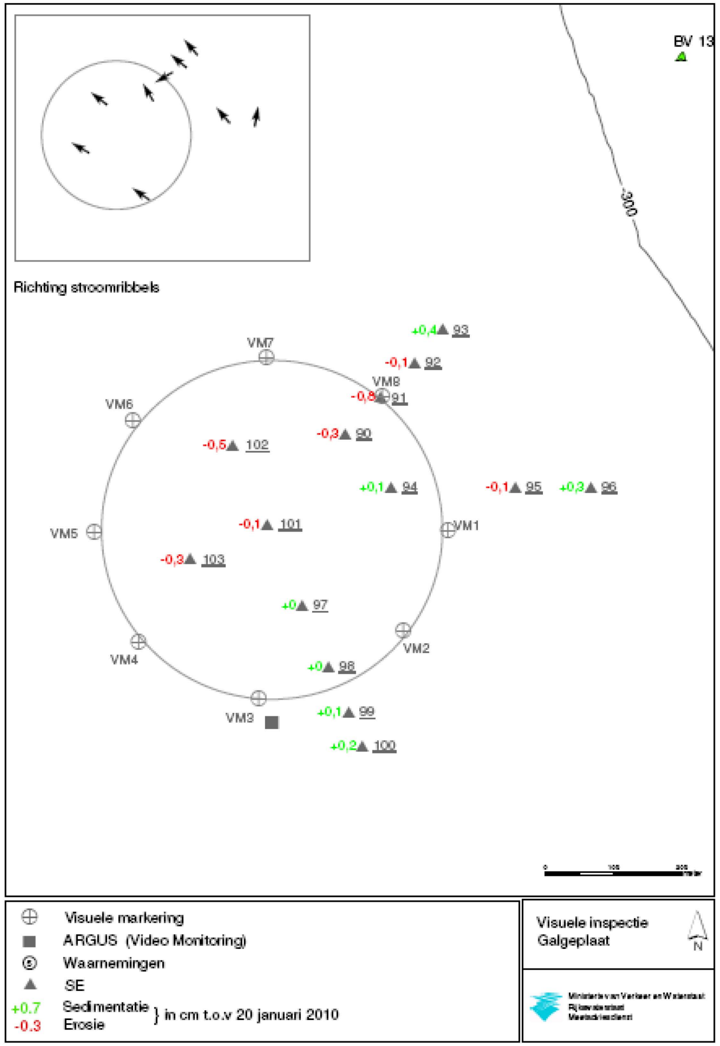
20 januari 2010

Waarnemingen: E. Parée en M. Bijleveld

Gasten: Jasper Dijkstra (Deltares)

(1) De rand van de suppletie bevat naast de slijpgeul bij VM4 een aantal plekken met drijfzand.

De apparatuur van de ARGUS is gereset. Er worden weer beeldopnamen gemaakt.



Visuele inspectie Galgeplaat

17 februari 2010

Waarnemingen: E. Parée en O. Sinke

Er zijn geen opmerkingen.

B Comparison measurement techniques bed level

The bed level along the profile derived with the different techniques is shown in the next figures.

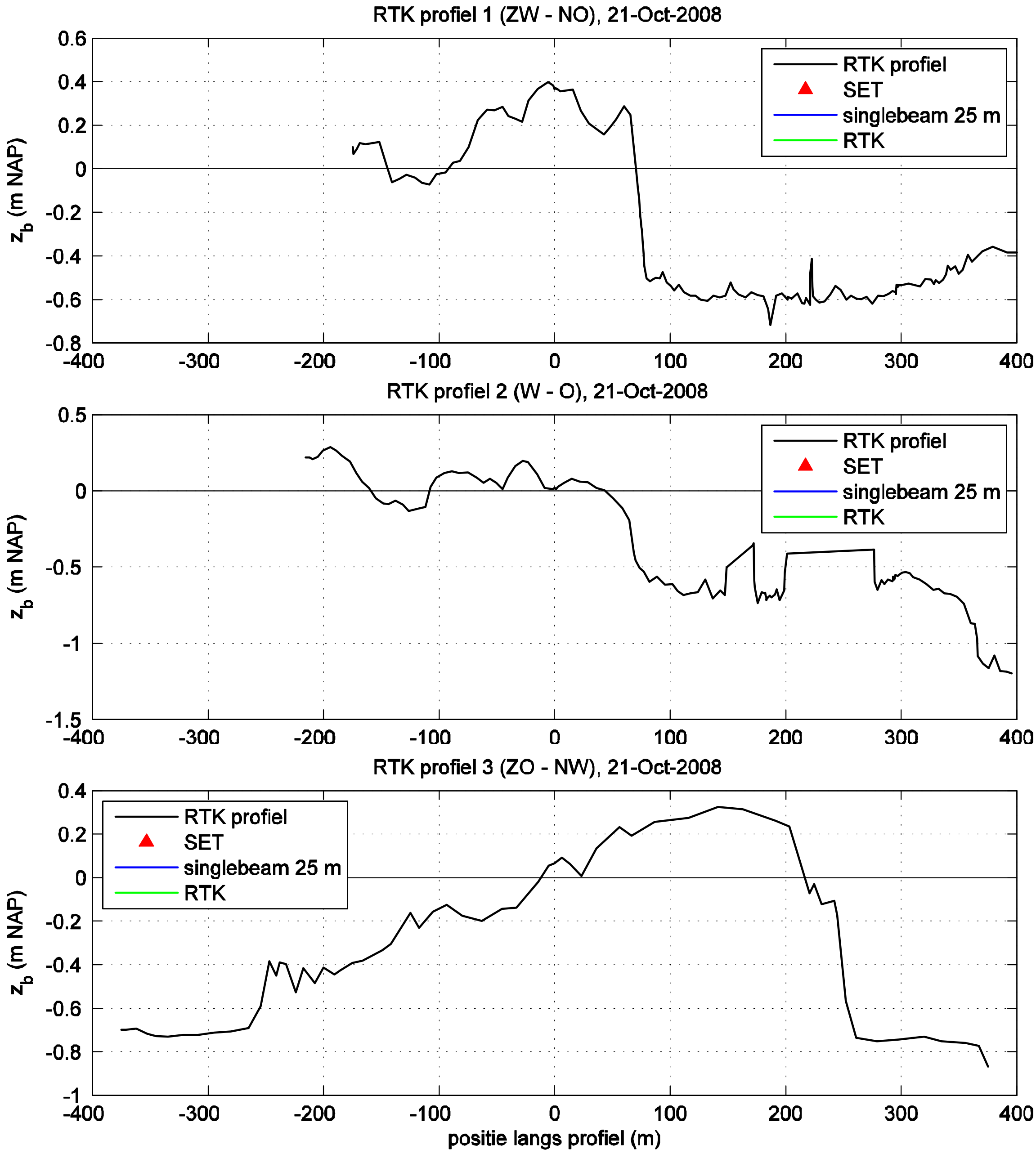


Figure B.1 Comparison of the bed level using different measuring techniques along the three profiles on 21 October 2008.

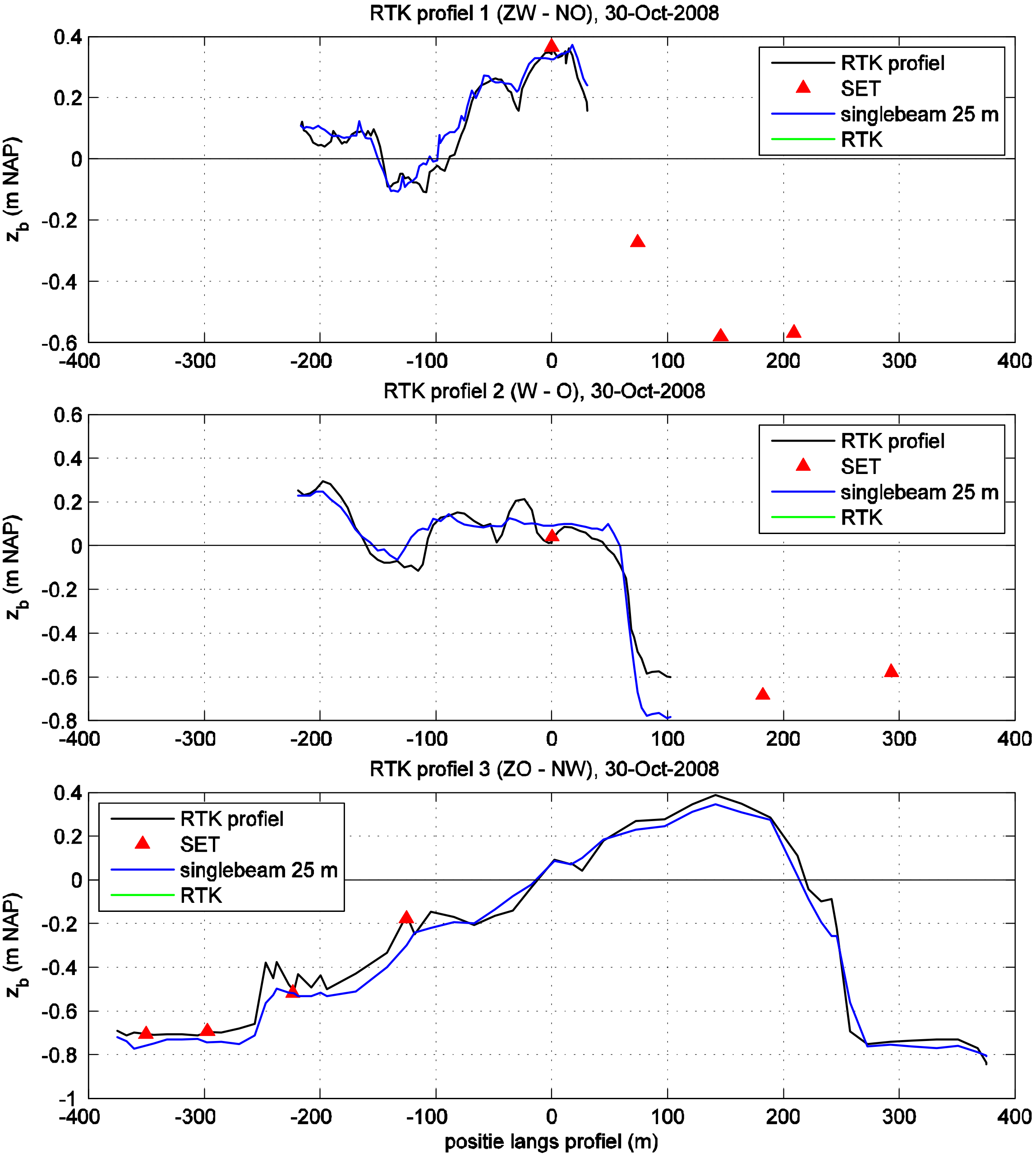


Figure B.2 Comparison of the bed level using different measuring techniques along the three profiles on 30 October 2008.

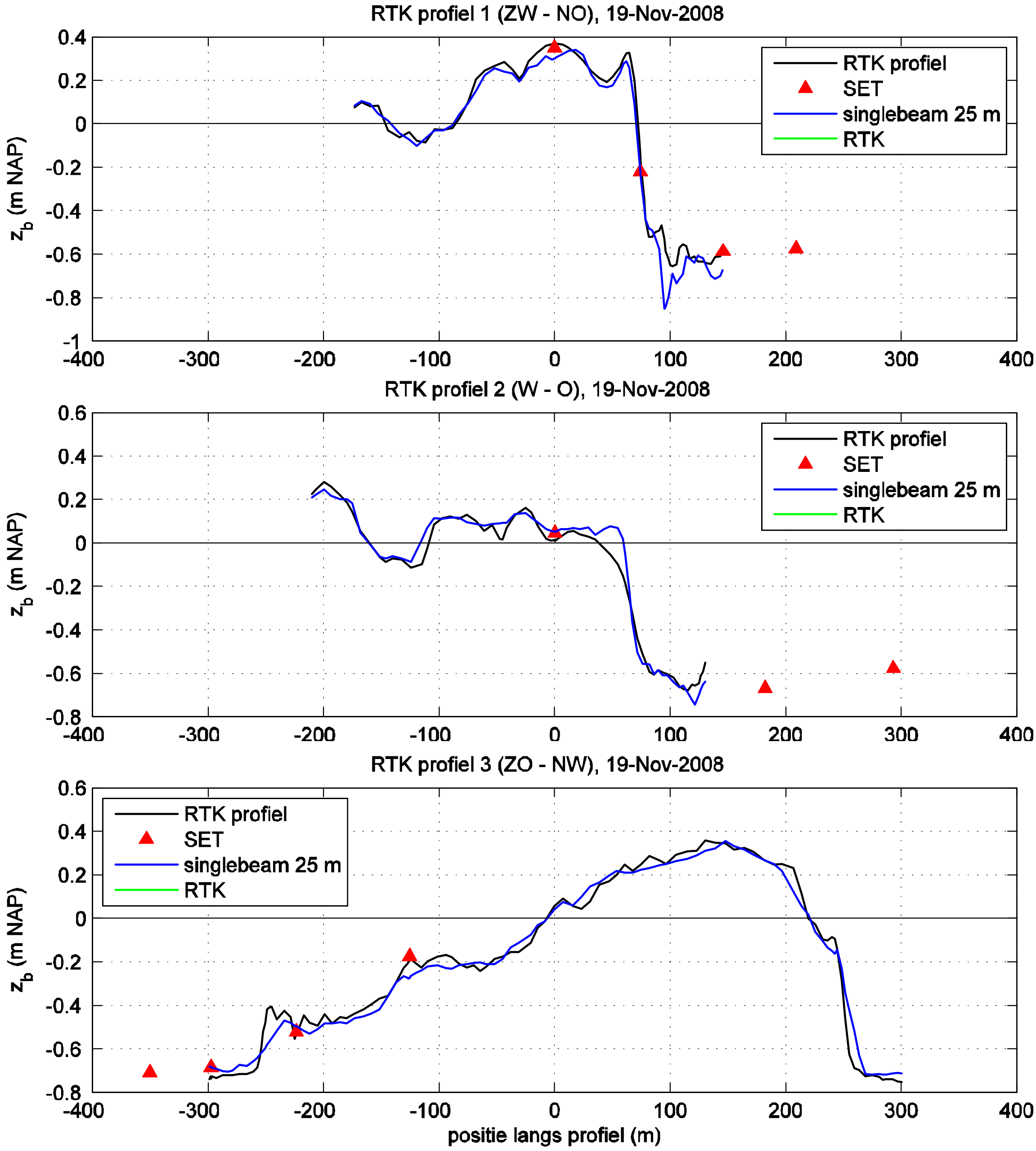


Figure B.3 Comparison of the bed level using different measuring techniques along the three profiles on 19 November 2008.

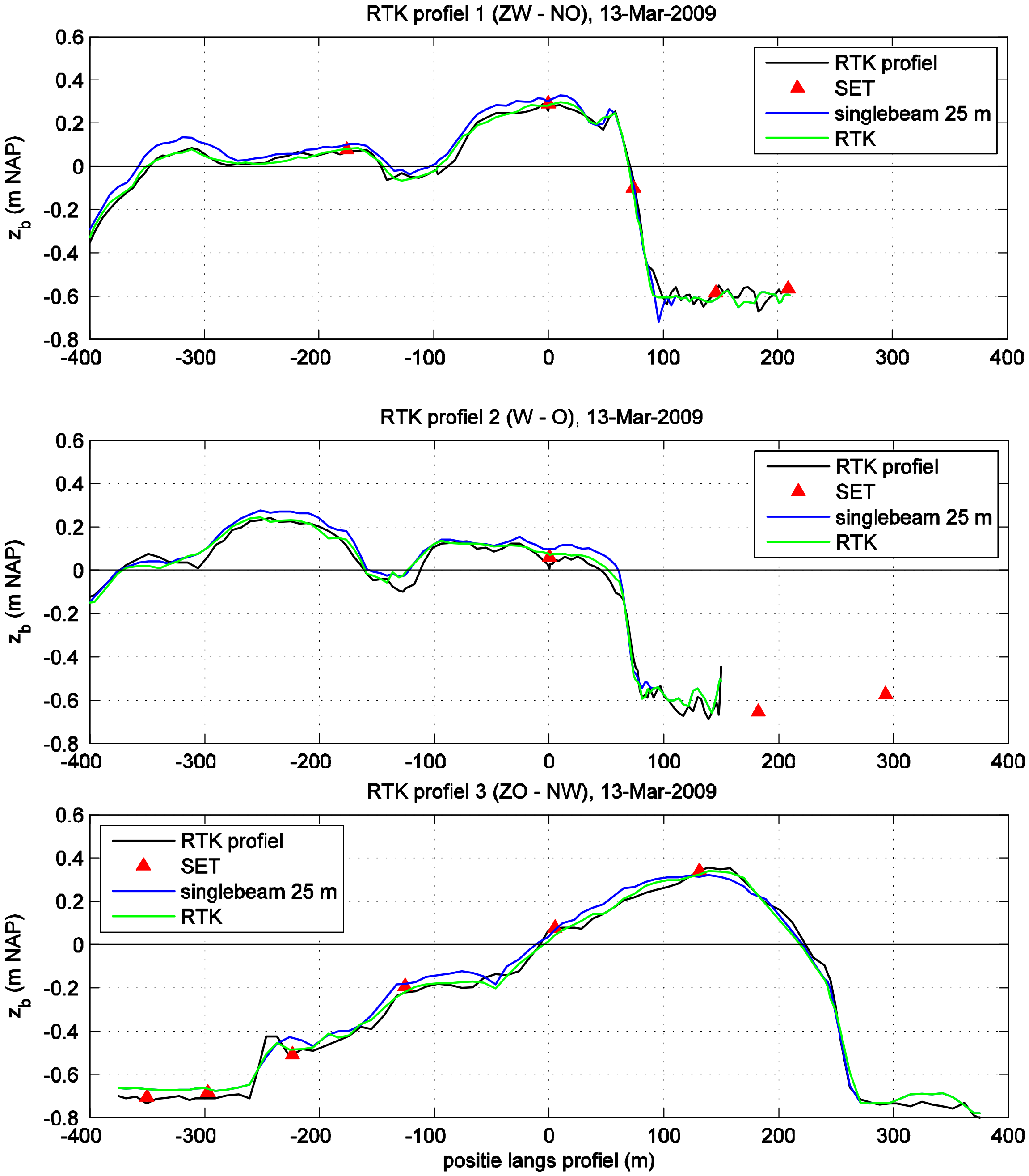


Figure B.4 Comparison of the bed level using different measuring techniques along the three profiles on 13 March 2008.

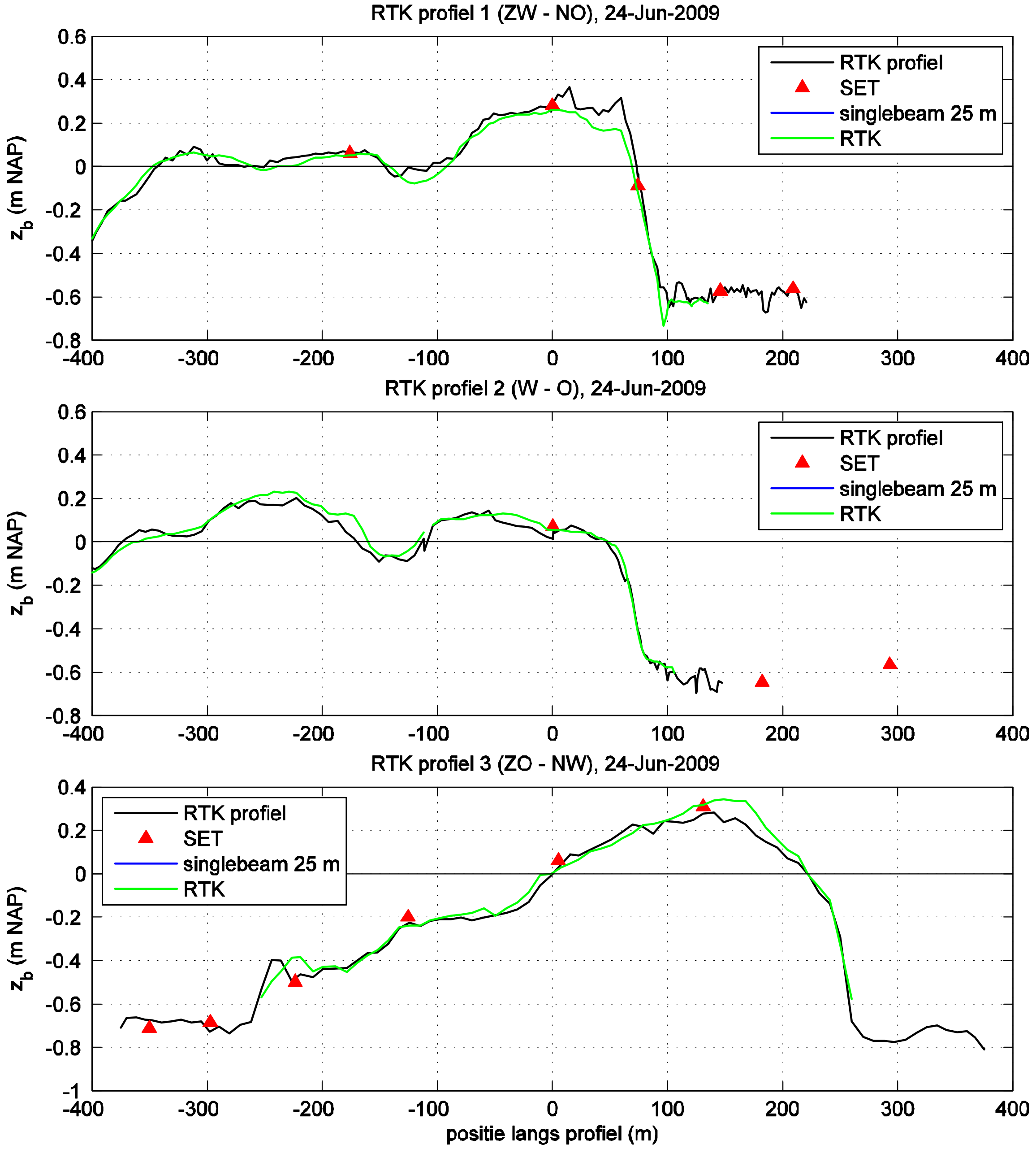


Figure B.5 Comparison of the bed level using different measuring techniques along the three profiles on 24June 2008.

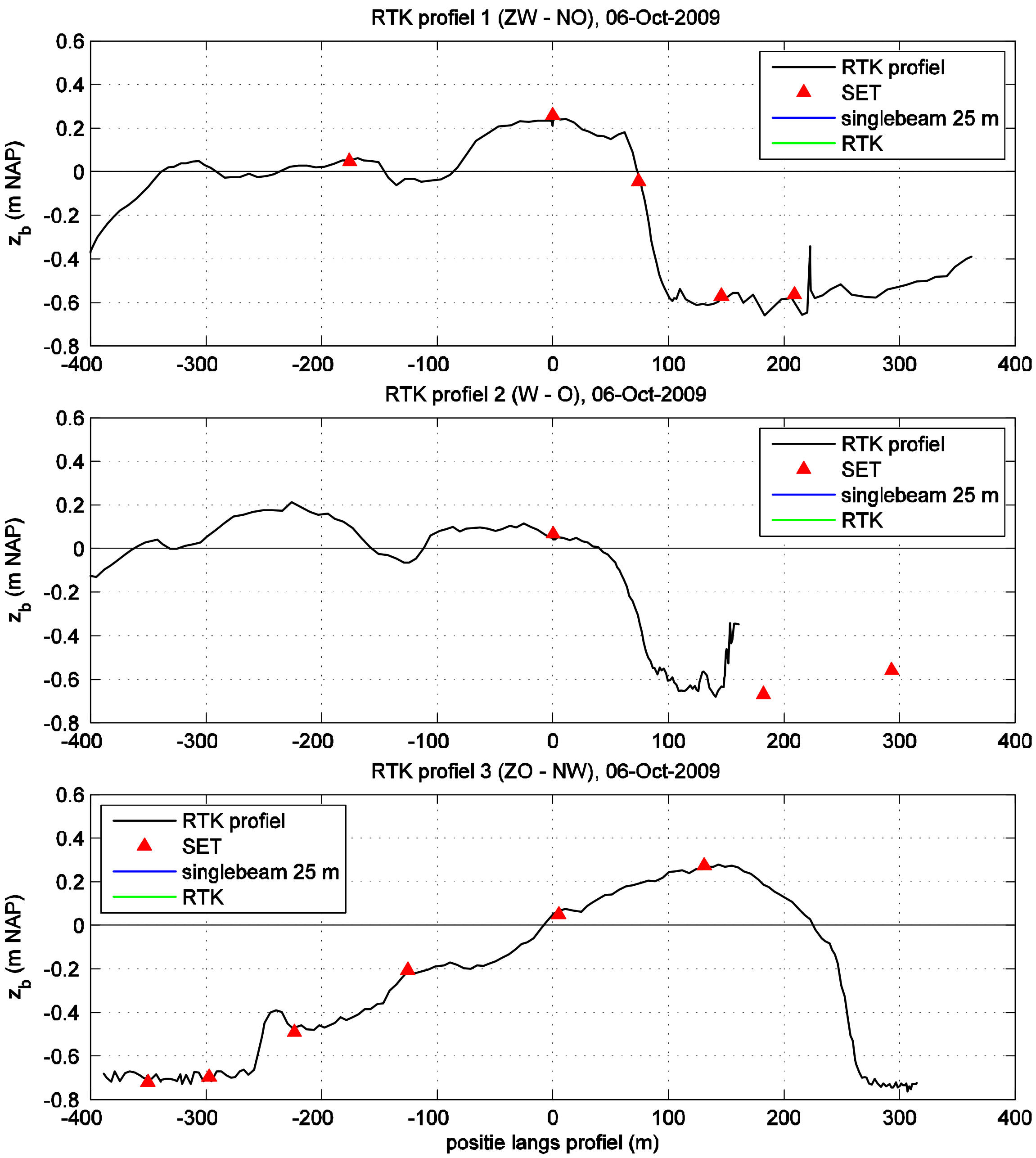


Figure B.6 Comparison of the bed level using different measuring techniques along the three profiles on 6 October 2009.

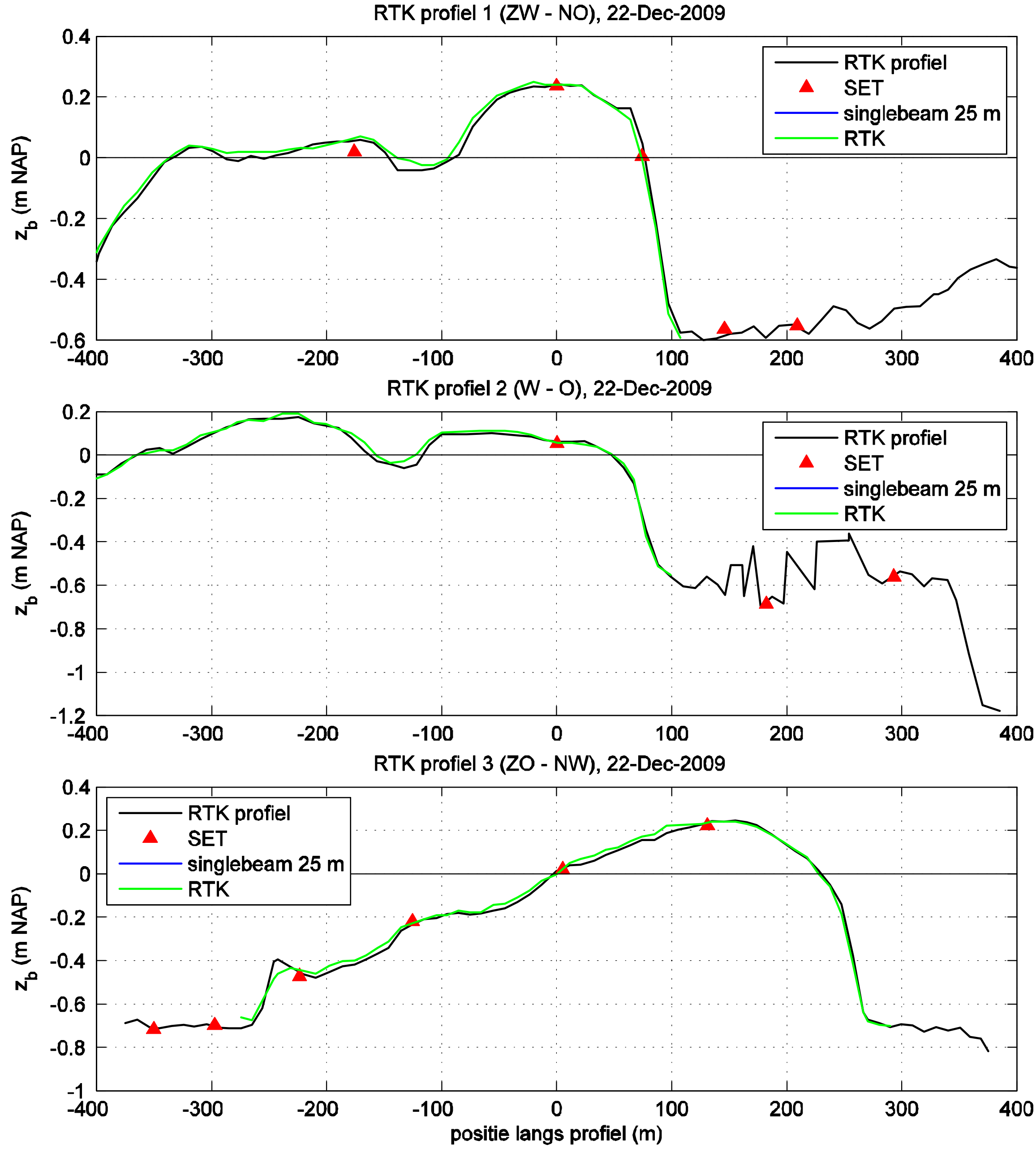


Figure B.7 Comparison of the bed level using different measuring techniques along the three profiles on 22 December 2009.

C Sediment composition

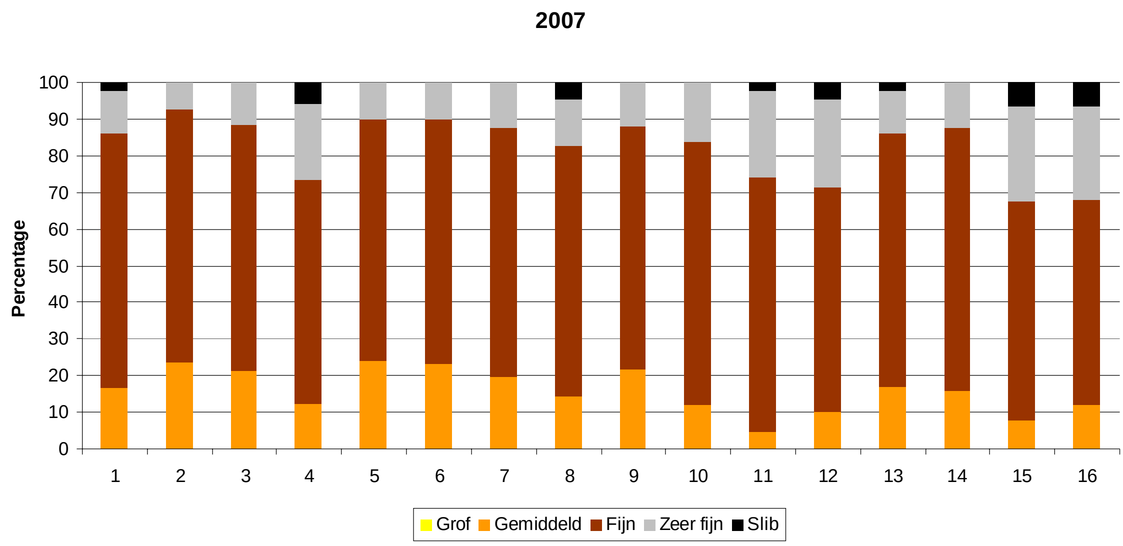


Figure C.1 Sediment composition 2007. (Coarse, Average, Fine, Very fine, Silt)

Table C.1 Grain size and silt fraction 2007

Loc.	SD(0,1) d (0,1)	SD(0,9) d (0,9)	SD50 ųm	SD50 phi	SPSA cm2/cc	SSD phi	Slit fraction					
							SSILT16 % silt	SSILT2 % silt	SSILT32 % silt	SSILT4 % silt	SSILT50 % silt	SSILT8 % silt
1	116,26	276,22	181,51	2,46	0,104	0,681	0,37	0	2,33	0	2,39	0
2	131,61	297,89	198,14	2,34	0,081	0,652	0	0	0	0	0	0
3	121,56	293,83	188,9	2,4	0,086	0,709	0	0	0	0	0	0
4	91,4	261,06	161,65	2,63	0,185	0,803	2,8	0,02	5,4	0,6	5,61	1,52
5	124,63	302,19	194,28	2,36	0,083	0,712	0	0	0	0	0	0
6	124,52	299,97	192,92	2,37	0,084	0,707	0	0	0	0	0	0
7	119,92	287,26	185,35	2,43	0,087	0,702	0	0	0	0	0	0
8	107,78	266,87	175,11	2,51	0,16	0,697	2,15	0	4,29	0,49	4,47	1,32
9	121,15	294,56	188,97	2,4	0,086	0,714	0	0	0	0	0	0
10	114,46	258,39	172,05	2,54	0,093	0,651	0	0	0	0	0	0
11	102,11	222,4	152,62	2,71	0,123	0,614	0,79	0	2,46	0	2,46	0
12	91,18	249,46	156,45	2,68	0,181	0,778	2,7	0	4,74	0,58	4,76	1,45
13	116,54	277,41	182,11	2,46	0,104	0,683	0,47	0	2,35	0	2,4	0
14	120,46	271,46	180,98	2,47	0,089	0,649	0	0	0	0	0	0
15	84,3	239,02	149,91	2,74	0,205	0,785	3,29	0,02	6,53	0,67	6,7	1,67
16	80,84	259,86	154,47	2,69	0,2	0,885	3,19	0,02	6,09	0,65	6,33	1,62

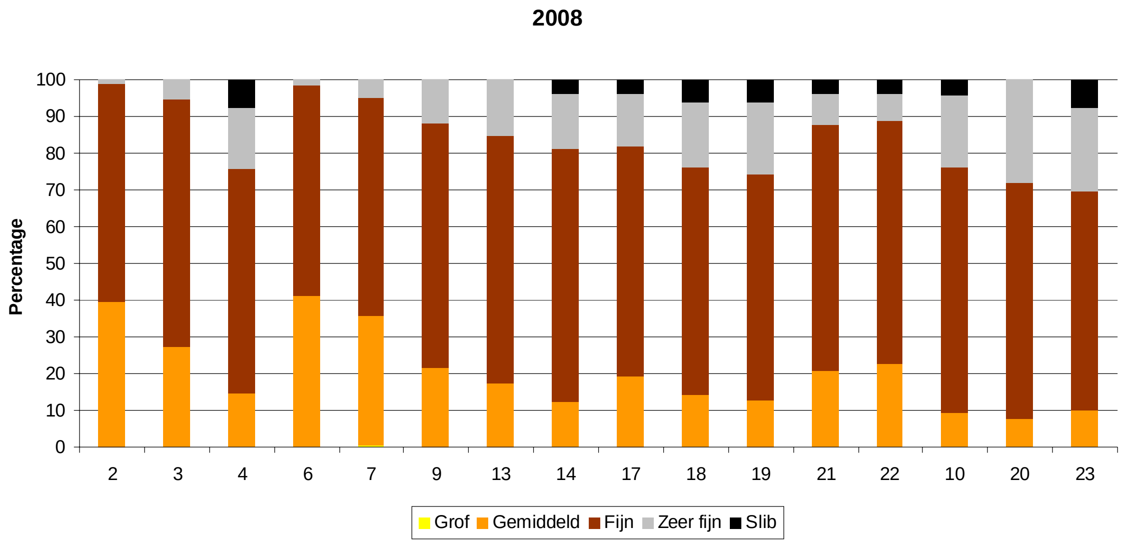


Figure C.2 Sediment composition 2008. (Coarse, Average, Fine, Very fine, Silt)

Table C.2 Grain size and silt fraction 2008

Loc	SD(0,1) d (0,1)	SD(0,9) d (0,9)	SD50 ųm	SD50 phi	SPSA cm2/cc	SSD phi	Silt fraction					
							SSILT16 % silt	SSILT2 % silt	SSILT32 % silt	SSILT4 % silt	SSILT50 % silt	SSILT8 % silt
2	160,52	334,05	231,58	2,11	0,07	0,58	0,00	0,00	0,00	0,00	0,00	0,00
3	136,90	308,67	205,72	2,28	0,08	0,65	0,00	0,00	0,00	0,00	0,00	0,00
4	88,80	270,71	168,49	2,57	0,22	0,81	4,26	0,11	7,54	0,91	7,83	2,29
6	156,26	346,11	232,86	2,10	0,07	0,63	0,00	0,00	0,00	0,00	0,00	0,00
7	139,95	342,11	219,23	2,19	0,07	0,72	0,00	0,00	0,00	0,00	0,00	0,00
9	120,87	295,03	189,04	2,40	0,09	0,72	0,00	0,00	0,00	0,00	0,00	0,00
13	114,70	279,42	179,29	2,48	0,09	0,72	0,00	0,00	0,00	0,00	0,00	0,00
14	106,45	258,41	170,49	2,55	0,16	0,69	1,88	0,00	3,76	0,49	3,80	1,21
17	105,78	288,16	180,14	2,47	0,15	0,78	2,01	0,00	3,80	0,47	3,90	1,23
18	94,26	269,49	167,64	2,58	0,19	0,80	3,21	0,02	5,90	0,70	6,15	1,79
19	91,73	263,02	163,55	2,61	0,19	0,80	3,18	0,02	5,90	0,68	6,03	1,70
21	119,08	290,79	190,49	2,39	0,14	0,69	1,83	0,00	3,64	0,39	3,83	1,20
22	121,47	296,69	194,53	2,36	0,14	0,69	1,91	0,00	3,72	0,41	3,95	1,26
10	99,19	245,88	160,78	2,64	0,19	0,70	2,72	0,03	4,39	0,78	4,39	1,72
20	99,23	237,89	153,20	2,71	0,11	0,70	0,00	0,00	0,00	0,00	0,00	0,00
23	81,58	249,76	154,73	2,69	0,25	0,82	4,99	0,20	7,80	1,14	7,84	2,70

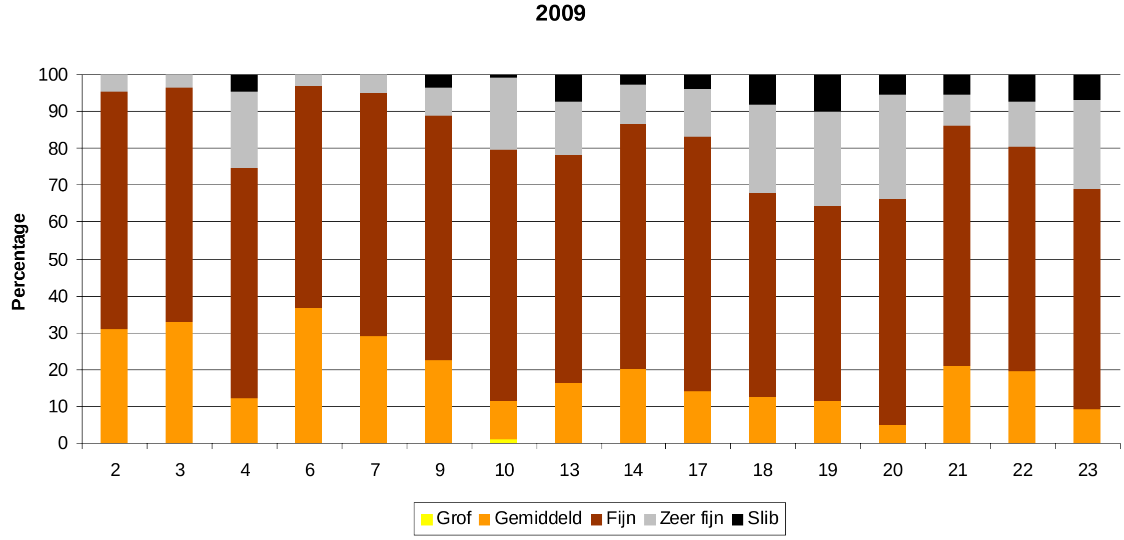


Figure C.3 Sediment composition 2009. (Coarse, Average, Fine, Very fine, Silt)

Table C.3 Grain size and silt fraction 2009

Loc	SD(0,1) d (0,1)	SD(0,9) d (0,9)	SD50 ųm	SD50 phi	SPSA cm2/cc	SSD phi	Silt fraction					
							SSILT16 % silt	SSILT2 % silt	SSILT32 % silt	SSILT4 % silt	SSILT50 % silt	SSILT8 % silt
2	140,87	319,83	212,23	2,24	0,08	0,66	0	0	0	0	0	0
3	144,38	324,6	216,38	2,21	0,07	0,65	0	0	0	0	0	0
4	94,98	260,18	162,99	2,62	0,19	0,78	2,92	0,03	4,73	0,78	4,75	1,78
6	148,33	337,74	223,9	2,16	0,07	0,66	0	0	0	0	0	0
7	138,3	315,24	208,82	2,26	0,08	0,66	0	0	0	0	0	0
9	122,44	296,01	194,36	2,36	0,14	0,68	1,66	0	3,21	0,4	3,36	1,18
13	107,68	256,64	165,48	2,6	0,12	0,69	0,67	0	0,67	0,27	0,67	0,65
14	94,97	277,76	173,47	2,53	0,23	0,8	4,36	0,14	6,95	1,11	7,11	2,62
17	116,62	289,4	187,05	2,42	0,12	0,71	1,05	0	2,61	0,22	2,66	0,65
18	109,8	266,3	175,5	2,51	0,16	0,69	2,04	0	3,79	0,53	3,83	1,34
19	76,09	264,21	155,21	2,69	0,26	0,92	4,71	0,26	7,5	1,19	7,65	2,65
21	62,55	257,66	149,49	2,74	0,35	0,96	5,78	0,66	9	1,73	9,33	3,39
22	87,63	221,61	145,05	2,78	0,22	0,71	3,55	0,13	5,29	1,05	5,29	2,1
10	114,24	291,48	190,04	2,39	0,18	0,71	3,07	0,03	5,12	0,76	5,34	1,94
20	97,29	290,6	180,19	2,48	0,21	0,81	3,79	0,11	6,67	0,86	7,14	2,18
23	83,69	246,9	153,34	2,7	0,25	0,81	4,47	0,23	6,96	1,21	6,99	2,59