Evaluation of Nourishments at Egmond with Argus Video Monitoring and Delft3D-MOR

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Z2822/July 2002
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ABSTRACT:

Regions of the Dutch coast suffer from structural losses of sand caused by the influence of tide and waves. To maintain the position of the coastline beach nourishments are applied. Around Egmond however, the nourished sand disappears relatively fast: former maintenance nourishments with a design life span of five years lasted only for two years. In the summer of 1999 besides a beach nourishment a shoreface nourishment has been applied. To be able to monitor the development of the nourishments with high resolution in time (and space), an Argus Station was installed on top of the lighthouse ‘Jan van Speijk’ in May 1999.

The first part of this study focuses on the application of Argus video images to analyse the development of the coastal area at Egmond. In the second part of this study the numerical model Delft3D is used to gain insight into the coastal processes at Egmond. Main objectives of this study are to evaluate the effect of the shoreface nourishment on the morphodynamics at Egmond and to evaluate to what extent the outer bar governs the development on the beach.

With the help of Argus Video Monitoring techniques morphologic changes are analysed over the period of June 1999 to September 2001. Generally, during the stormy winter months the intertidal beach retreats while during the calm summer months beach recovery is observed. North of the Argus station the beach is subject to accretion, while erosion is found at the southern side. This shape of the intertidal beach remains virtually constant throughout the seasons. The beach nourishment which has been applied at the end of June 2000 was not ‘adopted’ by the system. A few months later most of the nourished sand has disappeared out of the intertidal beach.

Merged images (time-averaged images) have been collected on a monthly basis to study bar dynamics. These images indicate a depression in the outer bar crest elevation south of the Argus station while north of the Argus station the elevation of the outer bar crest is clearly higher. A depression of the outer bar is associated with erosion (due to increased wave attack) and vice versa.

The Delft3D model was used to compute tide-averaged longshore transport gradients within the inner nearshore zone. Although transport rates are small during low wave conditions, gradients in tide-averaged longshore transport are much (about 2 times) larger than during high wave conditions. The results of the tide-averaged longshore transport gradients show a pattern of erosion and accretion which matches well with the shape of the intertidal beach.

Based on the interpretation of the observations obtained with the Argus Video Monitoring techniques and the result of Delft3D the following hypothesis is defined: high waves dominate the morphological development of the intertidal beach due to alongshore gradients in the outer bar crest elevation causing the typical shape of the intertidal beach while during low wave conditions longshore transport contribute to this pattern of erosion and accretion.

REFERENCES: Delft Cluster Project 03.01.03
Preface

This report describes a study which is accomplished within the framework of my M.Sc. thesis and completion of the study Civil Engineering at the Faculty of Civil Engineering and Geosciences, Hydraulic and Offshore Engineering Division of Delft University of Technology.

This study concerns the evaluation of nourishments at Egmond aan Zee, The Netherlands, which was carried out with the help of Argus Video Monitoring and the numerical model Delft3D. The study has been carried out at WL | Delft Hydraulics and was funded by the Delft Cluster Project Coasts (03.01.03) and the Co-operation Framework of Rijkswaterstaat / RIKZ and WL | Delft Hydraulics for Coastal Research (VOP-project). It received co-funding from the EU-sponsored COASTVIEW project under contract number EVK3-CT-2001-00054.

I would like to thank my supervisors, prof.dr.ir. M.J.F. Stive (Delft University of Technology), ir. S.G.J. Aarninkhof (WL | Delft Hydraulics), drs. S. Hoogewoning (Rijkswaterstaat RIKZ) and ir. G. Klopman (Delft University of Technology) for sharing their knowledge and support during this study. Furthermore, I am very grateful for the opportunity WL | Delft Hydraulics has offered me to complete my study at their institute and I would like to thank my temporary colleagues and fellow graduate students at WL | Delft Hydraulics for showing their interest and making my stay a very pleasant one. Finally I would like to thank my family and friends for their support during the years I spent in Delft.

Delft, July 2002

Leann Nipius
Summary

Regions of the Dutch coast suffer from structural losses of sand caused by the influence of tide and waves. To maintain the position of the coastline beach nourishments are applied. Around Egmond however, the nourished sand disappears relatively fast: former maintenance nourishments with a design life span of five years lasted only for two years. In the summer of 1999 besides a beach nourishment a shoreface nourishment has been applied. To be able to monitor the development of the nourishments with high resolution in time (and space), an Argus Station was installed on top of the lighthouse ‘Jan van Speijk’ in May 1999.

The first part of this study focuses on the application of Argus video images to analyse the development of the coastal area at Egmond. This part of the study continues on the work initiated by Caljouw (2000) who also used the Argus Video Monitoring techniques to evaluate the development of the combined beach and shoreface nourishment at Egmond. Caljouw suggested that the outer bar governs the development on the beach. In the second part of this study the numerical model Delft3D is used to gain insight into the coastal processes at Egmond. Main objectives of this study are to evaluate the effect of the shoreface nourishment on the morphodynamics at Egmond and to evaluate to what extent the outer bar governors the development on the beach.

With the help of Argus Video Monitoring techniques morphologic changes are analysed over the period of June 1999 to September 2001. Intertidal beach profiles have been gathered on a monthly basis. This set of profiles provides a good impression of the changing morphology at the intertidal beach. Generally, during the stormy winter months the intertidal beach retreats while during the calm summer months beach recovering is observed. North of the Argus station the beach is subject to accretion, while erosion is found at the southern side. This shape of the intertidal beach remains virtually constant throughout the seasons. The beach nourishment which has been applied at the end of June 2000 was not ‘adopted’ by the system. A few months later most of the nourished sand has disappeared out of the intertidal beach.

Merged images (time-averaged images) have been collected on a monthly basis to study bar dynamics. These images indicate a depression in the outer bar crest elevation south of the Argus station while north of the Argus station the elevation of the outer bar crest is clearly higher. A depression of the outer bar is associated with erosion (due to increased wave attack) and vice versa.

The Delft3D model was used to compute tide-averaged longshore transport gradients within the inner nearshore zone. Although transport rates are small during low wave conditions, gradients in tide-averaged longshore transport are much (about 2 times) larger than during high wave conditions. The results of the tide-averaged longshore transport gradients show a pattern of erosion and accretion which matches well with the shape of the intertidal beach.

Based on the interpretation of the observations obtained from the Argus Video Monitoring techniques and the results of Delft3D the following hypotheses are defined:

- High waves dominate the morphological development of the intertidal beach – due to alongshore gradients in the outer bar crest elevation alongshore variation in cross-shore transport occurs, causing the typical shape of the intertidal beach.
- During low wave conditions longshore transport contribute to this pattern of erosion and accretion.
Two reasons can be given why after the completion of the shoreface nourishment the nourished sand disappears relatively fast out of the intertidal beach, especially between $Y = 200$ m and $Y = 1000$ m:

- The nourishments have not affected the depression in the outer bar crest elevation, which is primarily responsible for gradients in sediment transport.
- During low wave conditions the gradients in longshore transport are not taken away by the shoreface nourishment, they may even increase.

It is recommended to continue monitoring with the Argus Video Monitoring techniques to better understand the morphodynamics at Egmond. Development of an intertidal beach indicator would be very useful for coastal managers who need simple objective indicators of the main beach system. Regarding the Delft3D Egmond model it is recommended to do more simulations under various wave conditions with a more recent bathymetry.
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1 Introduction

1.1 General

The defence structure of the Dutch coast against the sea is mainly formed by a sandy coast. In these areas of bars, beaches and dunes, which are constantly under the influence of the elements of wind and water, a variety of morphodynamic processes takes place. The ongoing occurrence of erosion events and periods of accretion makes that the nearshore zone is always changing and justifies periodic monitoring of the coast.

1.2 Problem description

Regions of the Dutch coast suffer from structural losses of sand caused by the influence of tide and waves, resulting in local retreat of the coastline. In 1990 the Dutch government decided to mitigate structural erosion and made it her policy to maintain the location of the coastline. The Basal Coastline (BCL) was introduced, corresponding to the location of the coastline at its position on the first of January 1990. When necessary nourishments are applied to maintain to this BCL.

Since the beginning of the coastal-maintenance-policy in 1990, several nourishments in the coastal area between IJmuiden and the Hondsbossche Zeewering were carried out to mitigate retreat of the coastline. The nourishments were designed with a lifespan of approximately five years. Around Egmond however, the nourished sand disappeared relatively fast: former maintenance nourishments lasted for only two years. The main reason for this is a seaward shifted Basal Coast Line at Egmond. Beach width at Egmond is relatively small and the buildings on the boulevard are close to the shore. With the seaward shifted BCL a buffer was created to reduce the risks of flooding. Furthermore, tourism and recreation benefit from this buffer as they demand for sufficient beach width.
Figure 1.1 shows the nourishment efforts between 1990 and 2000 for the coastal area between the Hondsbossche Zeewering and IJmuiden. Relatively frequent nourishments in Bergen and Egmond are clearly visible. The policy however is still to maintain a dynamic coast with long term nourishment programmes. Therefore alternative types of nourishments are investigated, which makes it necessary to better understand the coastal processes at Egmond and to study the behaviour and efficiency of nourishments.

In June 1999, besides a 200 m$^3$/m beach nourishment, a shoreface nourishment has been applied. This concerns a 400 m$^3$/m nourishment over a length of 2200 m at depths over 5 m, with its centre located around kilometre transect 38.00. To be able to monitor the development of both the beach and the shoreface nourishment with high resolution in time (and space), an Argus Station was installed on top of the lighthouse ‘Jan van Speijk’ in May 1999.

1.3 Approach

The first part of this study focuses on the application of Argus video images to analyse the development of the coastal area, and to better understand the coastal processes at Egmond. This part of the study continues the work initiated by Caljouw (2000). Caljouw used this technique to evaluate the development of the combined beach and shoreface nourishment at Egmond, between June 1999 and June 2000.

In the second part of this study process-based numerical models are used to gain insight into the complex 2- or 3-dimensional development and behaviour of sandy coastal systems. For this purpose the numerical model Delft3D is used.

1.4 Objective of this study

The Dutch coast near Egmond is typical for horizontally nearly uniform sandy beaches, dominated by 2 or 3 longshore breaker bars intersected by local rip channels.

Based on observations of the Argus video images, Caljouw defined the following hypotheses after evaluating the behaviour of the combined beach and shoreface nourishment at Egmond:

- **The former outer bar governs the morphological development of the beach.**

  In general, the elevation of the outer bar crest decreases with increasing distance offshore. It is assumed that the variation in distance between the shoreline and the outer bar, and consequently the alongshore variation in barheight of the outer bar, causes alongshore differences in wave dissipation and wave set-up. As a result, these variations may induce complex, 2DH flow patterns. Furthermore, at locations with a relatively high outer bar crest, the beach is to some extent sheltered against wave attack.

- **Shoreface nourishment disturbs the equilibrium.**

  The shoreface nourishment has to be considered as an extra breaker bar. The natural system of three breaker bars (2 bars and 1 swashbar) will be disturbed. In search for a new equilibrium the morphological system quickly responds.

The two hypotheses mentioned above form the starting point of this study. In line with this, the main objectives of this study are:

- To evaluate the effect of the shoreface nourishment on the morphodynamics at Egmond with the help of Argus video monitoring techniques and Delft3D.
- To evaluate to what extent the outer bar governs the development on the beach.
1.5 Layout of this report

Chapter 2 of this report starts with a description of the Egmond field site. Successively a description is given about the location of Egmond in the Netherlands, the hydrodynamic conditions, general morphology at Egmond, applied nourishments, available data and finally the Argus station installed at Egmond.

In Chapter 3 the Argus Video Monitoring techniques are presented. Image collection, qualification and processing, together with the Argus Tools used in this study, are discussed.

Application of the Argus Tools to Egmond is described in chapter 4. First a validation of the model of Intertidal Beach Mapping is given and next the morphologic changes observed with the help of the Argus Tools are described.

In Chapter 5 the set up of the Delft3D Egmond model and the simulations which are carried out are presented, followed by a description of the results.

Chapter 6 describes the evaluation of the morphologic changes at Egmond. Results from Argus Video Monitoring together with the Delft3D results, are evaluated.

General conclusions and recommendations are summarised in chapter 7.
2 Egmond field site

2.1 Introduction

The coastal zone of the Netherlands may be divided into three major regions, the Delta area, the Wadden area and the Holland coast (Figure 2.1). These regions differ both in morphological appearance and in the dominance of related physical processes. Egmond is located at the Holland coast which is the central part of the Dutch coast between Den Helder in the north and Hoek van Holland in the south. This coastal area is about 120 km long and consists mainly of sandy beaches and multiple barred nearshore zones. There are four major artificial works in the area, the harbour moles of Hoek van Holland, Scheveningen and IJmuiden and the Hondsbossche Sea Defence near Petten.

![Figure 2.1 Coastal areas of the Netherlands](image)

2.2 Egmond

Historically, the primary function of the Dutch coastal zone has been to provide safety against flooding of the hinterland. At Egmond coastal safety concerns the safety of the village itself, where the coastal defence strip has a cross-shore width of only 100 to 200 m in the area in front of the village. Residential homes and apartment complexes, one hotel, one school and some 10 semi-permanent beach cafes and restaurants at the dune foot represent important economic values at Egmond.
The coastal safety of the hinterland is not an issue. However, structural (long term) coastal erosion would affect the natural values of these areas for recreation and leisure and their role in the supply of drinking water.

### 2.3 Hydrodynamic conditions

The coast near Egmond aan Zee is located along the southern part of the semi-enclosed North Sea and is hydrodynamically characterized as a mixed-energy coast. A mixed-energy coast implies that both wind waves and tides act on the morphological characteristics in this area.

#### 2.3.1 Wind and wave climate

The prevailing wind direction is southwest (23%), followed by winds from the west (16%), east (13%) and northwest (12%) (Stolk, 1989). However, the most intensive storms, with large wind set-ups along the Holland coast come from north-western directions occurring mostly during the winter months.

The wave climate is closely related to the wind climate. The incoming wind waves at the Holland coast come from south-western to northern directions, as presented in the wave rose (Figure 2.2). Biggest waves come mainly from western to north-western direction. Besides this, the ‘fetch’ for the Holland coast is largest in north-western direction. The mean annual significant wave height is 1.3 m and the mean annual period is 5 s (Kroon, 1994).

![Wave rose of offshore light vessel 'Goeree'](image)

**Figure 2.2. Wave rose of offshore light vessel 'Goeree'**

#### 2.3.2 Tide

The semi-diurnal tide along the Holland coast induces a northward directed current during flood and southward directed current during ebb. The tidal curve is asymmetrical, with a flood period of 4 hours and an ebb period of 8 hours near Egmond (Figure 2.3). This tidal asymmetry is mainly caused by the interaction between the $M_2$ and $M_4$ tidal components. The mean tidal range is 1.65 m at Egmond while the maximum range at spring tide is 2.10 m and the minimum range at neap tide is 1.40 m (Kroon, 1994).
2.4 Morphology

In general, the beach profile around Egmond is a three bar system: two breaker bars in the surfzone and an intertidal (swash) bar (Figure 2.4). The most distinct one is the outer bar, at depths below NAP –3 m. Between the outer and inner bar a deep wide trough is situated reaching depths near NAP –6 m. The cross-shore distance between the outer bar crest and inner bar crest is about 300 m. The shape of the inner bar is less uniform and shows much variation in depth and in time. Rip-channels through the inner bar can be identified at different locations (Bijsterbosch, 2001). The trough between the inner bar and swash bar is less distinct compared to the offshore trough reaching depths of NAP –2 m and is about 100 m wide.

2.5 Nourishments

Since 1990 several beach nourishments have been applied at Egmond. In the period between 1990 and 2000 almost 2000 m³/m sand has been nourished. In 1999 besides a beach nourishment a shoreface nourishment was applied. Information about the nourishments, directly of interest for this study, is summarized in Table 2.1 (source: nourishment database RIKZ).

<table>
<thead>
<tr>
<th>Start of construction</th>
<th>Shoreface nourishment</th>
<th>Beach nourishment</th>
<th>Beach nourishment</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 June 1999</td>
<td>RSP 36.875 (Y=−1125 m)</td>
<td>April 1999</td>
<td>30 June 2000</td>
</tr>
<tr>
<td>8 Sept 1999</td>
<td>RSP 39.125 (Y=1125 m)</td>
<td>May 1999</td>
<td>5 July 2000</td>
</tr>
<tr>
<td>Northern boundary</td>
<td>RSP 36.875 (Y=−1125 m)</td>
<td>RSP 37.250 (Y=−750 m)</td>
<td>RSP 38.000 (Y=0 m)</td>
</tr>
<tr>
<td>Southern boundary</td>
<td>RSP 39.125 (Y=1125 m)</td>
<td>RSP 38.750 (Y=750 m)</td>
<td>RSP 38.800 (Y=800 m)</td>
</tr>
<tr>
<td>Characteristic volume</td>
<td>400 m³/m</td>
<td>200 m³/m</td>
<td>258 m³/m</td>
</tr>
<tr>
<td>Total volume</td>
<td>900,000 m³</td>
<td>300,000 m³</td>
<td>207,000 m³</td>
</tr>
</tbody>
</table>

Table 2.1 Beach and shoreface nourishments at Egmond between June 1999 and September 2001
2.6 Available data

2.6.1 Survey Campaigns

Bathymetric surveys of the beach and nearshore morphology around Egmond have been carried out during several campaigns. Table 2.2 presents an overview of the bathymetry data (x,y,z-datafiles) used in this study. Data has been gathered by:

- Wesp and ship soundings. The WESP (Water En Strand Profiler) is an 11 m high, motorised tripod on wheels with a platform at the top supporting the engine and a cabin with facilities. The surveys were conducted from the beach out to deeper water, making lanes with a spacing of about 50 m. The measurements were made to a maximum depth of about 7 m. Bathymetry data obtained by ship soundings was added to the WESP data in order to obtain a complete bathymetry data set.

- Landcruiser equipped with GPS. A GPS-signal receiver was used as a reference point, located on the top of a building high above the beach. An other GPS-signal receiver was placed on the front of a 4-wheel drive landcruiser. This GPS-system with reference station provides at least centimetre accuracy in X,Y and Z-direction. During two field campaigns shoreline datasets have been collected by driving along the shoreline taking into account the Argus data collection schedule. During the third field campaign bathymetry was measured driving stacks in longshore direction with a spacing of about 10 m.

<table>
<thead>
<tr>
<th>Date</th>
<th>Device</th>
<th>Bathymetry/Shorelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 May 1999</td>
<td>WESP and ship soundings</td>
<td>Bathymetry</td>
</tr>
<tr>
<td>14 September 1999</td>
<td>WESP and ship soundings</td>
<td>Bathymetry</td>
</tr>
<tr>
<td>29, 30 November 1999</td>
<td>Landcruiser GPS</td>
<td>Shorelines</td>
</tr>
<tr>
<td>14, 15 March 2000</td>
<td>Landcruiser GPS</td>
<td>Shorelines</td>
</tr>
<tr>
<td>November 2001</td>
<td>Landcruiser GPS</td>
<td>Bathymetry</td>
</tr>
</tbody>
</table>

Table 2.2 Surveyed data used in this study
2.6.2 Hydrodynamic database

Wave and tidal information is stored in hydrodynamic databases. These databases specifically hold the following information:

- measured waterlevel (m NAP);
- astronomical waterlevel (m NAP);
- root mean square waveheight (m);
- wave peak period (s);
- wave direction (deg N).

Since in absence of a gauge measuring waterlevels at Egmond, measured waterlevels at IJmuiden and Petten are interpolated linearly to obtain waterlevels present at Egmond (hereinafter named as station measurements).

To validate the accuracy of the station measurements, a comparison is made with data measured with a simple floating-gauge, temporarily installed directly outside the surfzone at Egmond. Due to malfunctioning of this gauge, its measurements are not fully reliable. Therefore station measurements are preferred over measurements of the gauge.

Figure 2.7 shows measurements of the floating-gauge, station measurements and astronomical predicted values.

![Figure 2.7 Waterlevels at Egmond](image)

As shown in Figure 2.7 the station measurements seem to be comparable to the measurements of the floating-gauge. Only at high tide water levels deviations are visible, which amount 0.1 m maximum. In conclusion: interpolating measured waterlevels at IJmuiden and Petten to obtain waterlevels present at Egmond give reliable and useful results.

Waveheight, wave period and wave direction data is gathered from a directional wave rider positioned at IJmuiden.
2.7 Egmond Argus station ‘Jan van Speijk’

In May 1999 the third Dutch Argus site became operational at Egmond aan Zee, North Holland (Figure 2.8). At the top of the lighthouse, named ‘Jan van Speijk’, five cameras are installed, pointing obliquely along the coastline. The system is located at an elevation of 43 m above sea level, covering a region of approximately 2.5 km within a 180° field of view along the Egmond beach.

![Figure 2.8 Location study area, lighthouse ‘Jan van Speijk’ and cameras on top of lighthouse](image)

The five cameras are connected to a computer, which controls the capture of images and automatically transfers the images from the remote site to the institute WL | Delft Hydraulics. Within the institute all images are stored within a structured archive by a host computer and forwarded to Rijkswaterstaat, RIKZ. All images of the Argus site ‘Jan van Speijk’ can be viewed at [http://www.wldelft.nl/argus](http://www.wldelft.nl/argus).

The installation was done by WL | Delft Hydraulics in assignment of Rijkswaterstaat Directorate North Holland. The Argus site is owned and maintained by Rijkswaterstaat.
3 Argus Video Monitoring

3.1 General

Until only a few years ago, all information on nearshore morphodynamics had to be gathered from comprehensive field experience. This way of data collection has some fundamental limitations. One problem is the fact that such experiments are relatively very expensive. Another, and – with respect to the physical interest of field measurements – even more important characteristic is the fact that the observation time scale is in practice limited to several weeks. Finally, surveying during severe weather and wave conditions is hardly possible. Continuously monitoring of the nearshore zone using video images seems to be a good alternative to get around these limitations of traditional measurement campaigns.

The history behind video imaging in nearshore studies probably goes back to the 1940s, where the first attempts to study coastal processes were made with the help of aerial photography. The large uncertainties which resulted from this technique were due to the very limited amount of images, often taken at a very irregular time interval. Moreover, knowledge of the connection between the visualization of the processes in an image and the underlying topography was limited. Since 1992, a new technique for the monitoring of coastal changes at the intertidal beach, the ARGUS program, is being developed, initiated by the Coastal Imaging Lab of the Oregon State University, USA.

This technique is based on video observations of a stretch of beach and is relatively cheap, as it only requires a system consisting of one or more digital cameras and a personal computer to control the cameras. Among over 20 stations around the world, an Argus video system is located at Egmond, along the Dutch coast.

This chapter gives an overview of the Argus video monitoring techniques which are used in this study to analyse the morphodynamics at Egmond. First the Argus station at Egmond, where video cameras are installed and images are collected, will be presented.

3.2 Image collection and qualification

The Argus station at Egmond is configured to collect basically three different types of images. Every daylight hour, a snapshot, a ten-minute time exposure image and a variance image are collected. These are discussed below.

3.2.1 Image types

Snap-shot image

The simplest image type is the snap-shot image. This image provides simple documentation of the general characteristics of the beach, but is not very useful to obtain quantitative information. An example of a snapshot image is shown in Figure 3.1 (first image).

Time-exposure image

A much more useful image type is the time-exposure or ‘timex’ image (Figure 3.1, second image). Time-exposure images are created by ‘averaging’ 600 individual snapshot images collected at a sample rate of 1 Hz (1 picture per second), for a period of 10 minutes. A lot of
quantitive information can be obtained from these images. Time exposures of the nearshore wavefield average out natural modulations in wave breaking, to reveal a smooth band of white which has been shown to be a good proxy for the underlying, submerged sand bar topography. Moreover they can be used to estimate the time-averaged position of the shoreline.

Figure 3.1 Snapshot, time exposure image and variance image

Variance image

Whereas the time-exposure is an ‘average’ of many individual snapshot images, the corresponding variance image displays the variance of light intensity during the same 10 minute time period.

Although not used in this study the variance images are useful at some specific coastal sites for analysis techniques since they indicate locations of time changing image intensity. An example of a variance image is shown in Figure 3.1 (third image).
### 3.2.2 Image processing

Fundamental to the use of images to study coastal behaviour is the conversion between image coordinates \((U,V)\) and the corresponding real-world ground coordinates \((X,Y,Z)\). Therefore the \(Z\)-coordinate is set to a user-defined level (mostly \(Z = 0\)) and images are mapped on that ground plane, what is called rectification. The derivation of the equations used for rectification of an oblique image is presented after Lippmann and Holman (1989) (Appendix A).

The Argus station makes use of a local system of axes. The origin is located within a meter of RSP 38.00. The \(Y\)-axis is parallel to the shore and positive to the south, the \(X\)-axis is parallel to the shore normal and positive in offshore direction and orientated at \(278^\circ\) from the north. The origin of the Argus camera’s is located at \((-100,-100)\).

![Argus system of axes](image)

**Figure 3.2 Argus system of axes**

Since the start of the Argus program, the video images from multiple Argus stations have been used for coastal research. This resulted, depending on the research goals, in all sorts of image analyses techniques. In continuation of this and especially within the framework of Argus for coastal management some interesting and useful tools have been developed (Aarninkhof, 1999):

- Intertidal Beach Mapping (IBM);
- Argus Merge Tool (AMT);
- Argus Stack Tool (AST).

The tools listed above, all used in this study, are described in section 3.3, 3.4 and 3.5 respectively.
3.3 Intertidal Beach Mapping

3.3.1 Background of model

The model to map intertidal beach bathymetry is basically funded on two independent submodels: the Shoreline Detection Model and the Shoreline Elevation model. The first model identifies the horizontal location of the shoreline from full-colour ARGUS video images, whereas the second model estimates its associated elevation from the hydrodynamics. If multiple shorelines are mapped over a tidal cycle, intertidal beach bathymetry data can be obtained. This is schematised in the flow diagram below.

Both the models are shortly discussed in the next paragraphs.

3.3.2 Shoreline Detection Model

In search of a technique to map intertidal beach bathymetries from shorelines, several researchers have developed methods to identify the horizontal location of the shoreline from video images. The method according to Plant and Holman for example, yields accurate results at beaches which show a well-pronounced shoreline break. However, such a shoreline break is often absent on mildly sloping beaches with emerging inner bars, which are commonly observed along the Dutch coast.

For this reason, Aarninkhof and Roelvink developed a new technique, which makes use of the colour difference between the dry and wet beach. First a region of interest (ROI) has to be
The model categorizes all pixels within the region of interest on the basis of a discriminator function. The discriminator function $\psi$ yields positive values at the dry beach and negative values at the wet beach. The location of the shoreline coincides with the locations where $\psi$ changes sign. The latter can be determined with the help of surface contouring techniques. This yields a raw estimate of the position of the shoreline in terms of image coordinates of the oblique image. Using the equations for rectification presented after Lippmann and Holman, these screen coordinates are translated into real-world coordinates.

Figure 3.4 Image coordinates $(U, V)$ converted to real-world coordinates $(X, Y)$

The main principles of the shoreline detection model are elucidated in Appendix B.

### 3.3.3 Shoreline Elevation Model

The estimate of the elevation of the time-averaged location of the shoreline includes the contribution of four processes which play a role in the inner surf zone. In this respect Janssen (1997) identifies the tidal level, wave set-up, surf beat and swash motions. His approach is adopted here:

$$z_{\text{shoreline}} = z_{\text{SWL}} + \eta_{\text{shoreline}} + K_{\text{osc}} \cdot \frac{\Delta z_{\text{osc}}}{2}$$

In the expression above, $z_{\text{SWL}}$ represents the still water level immediately outside the surf zone and accounts for the tidal elevation and the wind-induced set-up of the mean water level. $\eta_{\text{shoreline}}$ is the wave set-up of the mean water level in the surf zone, computed from a wave decay model (e.g. Battjes and Janssen, 1978).

The third term in the expression represents the contribution of the oscillating processes surfbeat and swash, where $K_{\text{osc}}$ is an empirical coefficient ($-1 < K_{\text{osc}} < 1$) which accounts for different levels of swash exceedence. $K_{\text{osc}}$ is determined from model calibration against field data. The contribution $\Delta z_{\text{osc}}$ of the oscillating components is modelled by combining empirical expressions for the vertical excursion of surf beat and swash. Detailed background information on the computation of the shoreline elevation $z_{\text{shoreline}}$ can be found in Appendix C.

Wave and tidal information, needed for the shoreline elevation model to compute the shoreline elevation at any moment, is stored in hydrodynamic databases. These databases specifically hold the following information:

- measured waterlevel (m NAP);
- astronomical waterlevel (m NAP);
- root mean square waveheight (m);
- wave peak period (s);
- wave direction (deg N).

The current value of the still water level outside the surf zone $z_{\text{SWL}}$ is obtained from measured
data preferably, when not available astronomical predicted values are being used.

### 3.4 Argus Merge Tool

Another very useful post-processing tool is the Argus Merge Tool. Single time averaged Argus images are being rectified and joined together. This results in a plan view of the nearshore zone (Figure 3.5).

![Figure 3.5 Merged image](image)

The bright regions indicate regions of intense wave breaking hence the location of shallow water depth. In this way morphologic features like the shoreline and breaker bars can easily be identified. Within the Argus merge tool it is possible to specify the condition at which moments images are collected to create a merged image. The condition can either be a tidal level or a wave height, both user-defined.

Specifying a condition with wave heights bigger than 1.5 m produces merged images on which the bars are clearly visible by the smooth white bands at locations with a lot of wave breaking. These images are appropriate to analyse the behaviour of bars. When a low-tide level condition is specified, for example NAP -0.60 m, the rendered merged images are very useful to analyse the morphological features of the intertidal beach (like beach width).

### 3.5 Argus Stack Tool

The Argus Stack Tool automatically creates so called ‘stacked images’. These images are created by sampling intensities along one array, at one tidal level or at a specific wave height, in time. The array (in Figure 3.6) is chosen perpendicular to the coastline. The bright parts along that array indicate intense wave breaking hence the location of the bars. The movement of the dissipation patterns in time enables a quantitative impression of the bar dynamics for that transect.

![Figure 3.6 Stacked image](image)
4 Application of Argus Tools to Egmond

4.1 Introduction

In this chapter the Argus Tools described in chapter 3 are used to study morphological changes at Egmond, like intertidal beach morphology, beach width and bar behaviour. This is done for the period between June 1999 and September 2001.

First a validation is made of the model to map the intertidal beach.

4.2 Validation of Intertidal Beach Mapping

4.2.1 Model validation

Approach

The model of Intertidal Beach Mapping (IBM) is funded on two sub-models: the shoreline detection model and the shoreline elevation model. To assess the accuracy of the model the validation should address the two sub-models independently in order to find out which sub-model contributes most to the overall model deviations. Therefore, common beach elevation maps \((x,y,z)\) do not satisfy as a deviation between model and survey since a deviation obtained this way cannot be related to either the shoreline detection sub-model or the shoreline elevation sub-model (see Figure 4.1). For this reason, a data set of GPS-surveyed shorelines is collected at Egmond beach, resolving both the location and the elevation of the shoreline. The surveys were carried out simultaneously with the recording of the video images by the Argus station ‘Jan van Speijk’.

Based on the data set of GPS-surveyed shorelines, the two sub-models can be validated independently. The horizontal deviation \(dx\) is quantified from the difference between the shoreline detection model and the survey while the vertical deviation \(dz\) represents the error introduced by the shoreline elevation model. To be able to inter-compare the accuracy of the two sub-models all horizontal deviations are mapped on a vertical plane by making use of the mean beach slope \(m\) around the shoreline. Inaccuracies originating from either one of the sub-models are expressed as a vertical error \(\delta_v\) (Figure 4.2).
Assessment of deviations:

- Case 1 (perfect elevation): $\delta_v = m \cdot dx$
- Case 2 (perfect location): $\delta_v = dz$
- Case 3 (general case): $\delta_v = dz + m \cdot dx$

where $m$ is a representative beach slope.

Figure 4.2 Background of deviations

Results

The validation of the model is based on four days worth of survey-data: two days in November 1999 and two days in March 2000. The survey-data was collected by using a landcruiser, equipped with a GPS-system, driving along the shoreline taking into account the Argus data collection schedule. This means that a shoreline was surveyed at the same time the Argus station collected an image. The GPS-system provides at least centimetre accuracy in X, Y and Z-direction. During these campaign days the Argus station collected images at half an hour intervals.

Caljouw (2000) used the same approach to assess the accuracy of the model of Intertidal Beach Mapping (IBM). However the model has been renewed since. The area of interest in the image can be adjusted which was not possible with the old version of the model. Furthermore, the model capabilities to distinguish dry and wet parts of the beach were improved. Therefore a new validation of the model is needed and is carried out with two sets of data:

- One dataset identical to the set used by Caljouw. This means that only the moments Caljouw has detected a shoreline in IBM are used for the analysis;
- One dataset holding all the shorelines detected with IBM during the four survey days.

Since the surveyed and modelled shorelines consist of non-uniformly spaced X,Y-coordinates, all the shorelines are interpolated to a grid using 1D-interpolation. The deviations $dz$ and $dx$ can now be computed for all modelled shorelines every 2 meters longshore. Consequently $\delta_v$ can be determined using the relation: $\delta_v = dz + m \cdot dx$. The value of $m$ is based on measurements and is set to 0.025.

For all longshore locations with more than 5 values of $\delta_v$ the root mean square values of $\delta_v$ are plotted in Figure 4.3 and Figure 4.4 including the standard deviations of $\delta_v$. Figure 4.3 shows results using the Caljouw dataset while Figure 4.4 shows the results using the complete dataset.

Except for locations $Y < -700$ all mean deviations are smaller than 0.1 m. In a horizontal sense on a slope of 1:40 this means 4 m. Standard deviations are between 0.1 and 0.2 m. Like Caljouw explained, besides the inaccuracies introduced by the survey method, these kinds of errors seem very acceptable considering influences like:
- Pixel resolution: errors between 0 and 1 m cross-shore and 0 to 8 m longshore, this is most probably the reason for the increasing deviations with increasing distance from the cameras (Oude Elberink, 2001);
- Waterlevel variation within 10 minute intervals: cross-shore errors between 0 and 6 m;
- Errors brought in by using empirical formulas and estimations for modelling shoreline elevation: error unknown.

The jump in the results around Y = 200 can probably be explained by the complex system of gully’s and bars at that location, which makes it difficult to map the exact shoreline. The mapped shorelines can therefore not be considered to be very precise.

![Figure 4.4 Error statistics - Dataset holding all shorelines](image)

When looking at the results using the complete dataset, the mean deviations appear to be about twice as large, about 0.2 m, compared to the results using the Caljouw dataset. Standard deviations are the same, 0.1 to 0.2 m. This can be attributed to the following reasons:

- The Caljouw dataset consists of shorelines taken only at ‘perfect’ conditions. The region of interest was fixed and covered most of the image. Any disturbance on the image (rain drop on the lens, obstacles on the beach, shadows on the beach, etc) caused wrong modelling and the image was rejected. Since the region of interest can be adjusted within the renewed version of IBM, shorelines can be modelled under less optimal image quality conditions which may lead to larger errors in the mapped shorelines.
- However, adjusting the region of interest often means minimizing the region of interest and consequently less colour information can be obtained. In some cases this makes the model to define image intensities in black and white colour space instead of RGB colour space. As is known from visual observations the shoreline is modelled a little bit more seaward when using black and white colour space.

Although the increase of the number of shorelines, due to modelling under more various conditions, leads to larger errors in the modelling, it is still preferred to use as much shorelines as possible. The reason for this is to obtain shorelines over a full tidal cycle with preferably regular intervals.
4.2.2 Post-processing

Introduction

With the help of the Intertidal Beach Mapping tool it is possible to collect shorelines within the intertidal beach. By modelling multiple shorelines from Argus images within a tidal cycle it is possible to create an intertidal beach profile for that time (Figure 4.5). A series of profiles in time will give a good impression about the changing morphology. Note that basically every beach profile is build up of shorelines collected at one day at one tidal cycle.

Since the intertidal beach is a dynamic area with short-scale features, data obtained from modelled shorelines are generally irregularly - maybe quasi-regularly - spaced. Therefore, to create a beach profile with the collected shorelines, the data of all shorelines need to be interpolated to a regularly spaced grid.

For the period of June 1999 to June 2000 (the first 12 months after the installation of the Argus station) intertidal beach profiles are collected on a monthly basis by Caljouw (2000). The intertidal beach was mapped over a length of 1400 m alongshore (-700 m to 700 m in Argus coordinates) Mapped shorelines were interpolated to a regular spaced grid (yielding 2 m in cross-shore direction and 20 m in longshore direction) using linear interpolation, between NAP +0.0 m and NAP +1.0 m.

Within the framework of this study the Caljouw dataset of mapped intertidal beach profiles is extended to September 2001. However, with the renewed version of IBM it is possible to map shorelines over a larger range in both horizontal and vertical sense. Mapping of the shorelines was carried out over a length of 2000 m alongshore (-1000 m to 1000 m in Argus coordinates) with a vertical range of 1.4 m (NAP -0.4 m to NAP +1.0 m).

The shorelines are interpolated to a regular spaced grid using Loess interpolation instead of a linear interpolation method. In the next subsection a validation is made of the linear interpolation method and the Loess interpolation method. The next paragraphs discuss sub-sampling of the shoreline datasets, linear interpolation and Loess interpolation respectively.
Densely spaced shoreline data

The data set of the shorelines collected with IBM is densely spaced in longshore direction, varying from 0.25 m close to the Argus cameras to 20 m at 1000 m away from the cameras (Oude Elberink, Van Oort, 2001). In cross-shore direction the spatial density is in the order of 5 to 10 m depending on the intervals the shorelines are mapped with. To reduce the computational effort the data set of shorelines is first sub-sampled. The over-sampled data is decimated using a filter, which averages data over regions that are $\Delta x$ wide (Plant, 2001):

$$\sum_{i,j} z(\bar{x}_n) \cdot \delta\left(2\left(\frac{\bar{x}_n - \bar{x}_j}{\Delta x}\right)\right) \sum_{i,j} \delta\left(2\left(\frac{\bar{x}_n - \bar{x}_j}{\Delta x}\right)\right)$$

where $\delta$ is a function which returns 1 when the values of its argument are in the range $-1 < 2\left(\frac{\bar{x}_i - \bar{x}_j}{\Delta x}\right) < 1$, and it returns 0 otherwise.

This subsampled data set of shorelines is now ready to be interpolated to a regular spaced grid to obtain the intertidal beach profile. In the next two paragraphs a normal linear interpolation method and a more sophisticated Loess interpolation method is discussed.

Linear interpolation

The general interpolation problem consists of a set of $N$ observations, $z_j$, located at positions $\bar{x}_j$, and $N^*$ locations, $\bar{x}_i^*$, where we wish to obtain interpolation estimates. The independent variable is a vector because it can include multi-dimensional location coordinates, such as $\bar{X}=(x,y,t,...)$

The observation locations are mostly randomly spaced, while the interpolation locations are usually regularly spaced. If, in one spatial dimension, the separations between sequential observation locations are $\Delta x_n$, then the $j^{th}$ location is given by

$$x_j = x_1 + \sum_{n=1}^{j} \Delta x_n$$

where $x_1$ is the first observation and $\Delta x_1=0$ is assumed.

Linear interpolation methods seek an elevation estimate, $\hat{z}$ of the form

$$\hat{z}_i = \sum_{j=1}^{N} \hat{a}_{ij} z_j$$

which constructs the interpolated value as a linear combination of the observations. The parameters $\hat{a}_{ij}$ are a set of weights, which depend only on the location of the observations relative to the interpolation location.
Quadratic Loess interpolation

The approach taken here is to construct a quadratic surface, \( \hat{z}_i \), about each interpolation location, \( \bar{X}_i \) (Plant, 2001)

\[
\hat{z}_i(\bar{X}) = \hat{b}_0(i) + [\bar{X} - \bar{X}_i]^T \hat{b}_1(i) + [\bar{X} - \bar{X}_i]^T \hat{b}_2(i)
\]

Except for \( \hat{b}_0 \), which is the elevation estimate at the \( i \)th interpolation location, the quadratic model parameters may be vectors, in case of multi-dimensional location coordinates. Thus, \( \hat{b}_1 \) is the (column) vector of first order coefficients (which includes one element for each dimension), and \( \hat{b}_2 \) is the vector of second order coefficients in the quadratic model (which contains one element for each dimension, plus one element for each of the cross-products). Each of the parameter vectors is a function of space, and must be estimated at all \( N \) interpolation locations.

The quadratic parameters, \( \hat{b}_i \), are functions of the observations, and are estimated by minimizing the ‘local weighted mean square deviations between the model and the data’, in which the parameters solve the ‘generalized normal equations’ (Priestley, 1981). The weighted mean square deviations are

\[
Q^2 = \frac{1}{N} \sum_{j=1}^{N} \left[ \left( \hat{z}_j(\bar{X}_j) - z_j \right) W_{ij} \right]^2
\]

where \( W_{ij} \) are Loess weights (Greenslade et al., 1997) (Figure 2) are

\[
W_{ij} = \begin{cases} 
1 - (w_{ij})^3 & \text{if } w_{ij} < 1 \\
0 & \text{otherwise}
\end{cases}
\]

and

\[
w_{ij} = (\bar{X}_j - \bar{X}_i)^2 [L_{x}]^{-1}
\]

where \( L_x \) is the D-by-D (D is the number of dimensions in \( \bar{X} \)) diagonal matrix

\[
L_x = \begin{bmatrix}
(\lambda_x)^2 & 0 & 0 & \cdots \\
0 & (\lambda_y)^2 & 0 & \cdots \\
0 & 0 & (\lambda_z)^2 & \cdots \\
\vdots & \vdots & \vdots & \ddots
\end{bmatrix}
\]

Here, \( \lambda_x, \lambda_y, \ldots \) are (fixed) smoothing scales that determine the smoothness of the interpolated values in the corresponding dimensions. However, data obtained from the modelled shorelines are irregularly spaced. Large-scale features that are sampled sparsely and short-scale features that are sampled densely cannot simultaneously be preserved by choosing fixed smoothing scales. Therefore it is necessary to allow spatially varying smoothing scales.

The Loess interpolation method however, determines at every interpolation location the smoothing scales correlated to the sample spacing density.
4.2.3 Validation of interpolation methods

In this subsection a comparison is made between the accuracy of a normal linear interpolator and the Loess interpolator. The interpolated values are validated against ground-truth data. During a survey campaign in November 2001, ground-truth data is gathered using a landcruiser equipped with a GPS-system. In contrast to the survey campaigns in November 1999 and March 2000 when shorelines were measured, data is now collected along regularly spaced alongshore tracks.

To be able to make a reliable validation of the interpolated values, the survey data should not be interpolated to a regular spaced grid since interpolation in any way introduces inaccuracies. Therefore the mapped shorelines are interpolated to the data points (X,Y coordinates) of the surveyed data. This is done by using both linear interpolation and Loess interpolation. Consequently the interpolated values (Z-coordinates) can be validated with the (real) Z-coordinates of the surveyed data.

The area of interest is divided into sections of 20 m alongshore. For every section the mean deviation and standard deviation is computed of the deviation values present. The results according to the linear interpolation and Loess interpolation are plotted in Figure 4.7 and Figure 4.8 respectively.

As shown in the results in Figure 4.7 and Figure 4.8, the mean deviations are more or less equal with both interpolation methods and in the order of 0.3 m. However, the Loess interpolation method is showing more consistency than the linear interpolation method. Standard deviations are about 0.2 m and clearly smaller when using Loess interpolation instead of linear interpolation.
A deviation of 0.3 m in vertical sense corresponds with a horizontal deviation of 12 m (having a beach slope of 1:40, which is on the conservative side). This is acceptable since the width of the intertidal beach is in the order of 100 m.

Around Y = 100 m the mean deviations are significantly larger. This is probably due to the presence of gullies and bars in front of camera 3 which makes it hard to identify unambiguous waterlines at most tidal levels. Southward of Y = 400 m the mean deviation does not increase with increasing distance from the camera which is expected. Most probably this is due to the fact that only a few alongshore tracks are surveyed in that area. In November 2001 when the survey was carried out beachwidth was very small at that location.

In conclusion, compared to linear interpolation, the Loess interpolation method gives more accurate results. Another advantage of the Loess interpolator is that the obtained intertidal beach profiles have a much smoother appearance.

4.3 Intertidal Beach morphology

Appendix D shows contour plots of the intertidal beach profiles, gathered on a monthly basis, over the period of June 1999 to September 2001. Note that the profiles of June 1999 to June 2000 were already collected by Caljouw. Since the renewed version of IBM allows mapping of shorelines further away from the camera, the profiles of July 2000 to September 2001 cover a larger area than the Caljouw profiles. 3D plots of the intertidal beach are shown in Appendix E for each month between July 2000 and September 2001.

Caljouw observed the following different appearances, analysing the intertidal beach profiles for the period of June 1999 to June 2000:

- The coast stretches out around Y = -200 m and a gap appears near Y = 400 m;
- The first four months, June 1999 – September 1999, the location of the intertidal beach stays the same;
- The stormy season sets in October, the intertidal beach retreats at all longshore locations up to 30 m in November;
- In February and March 2000 the gap near Y = 400 m moves further onshore and the intertidal beach even reaches the dunes at that location;
- In April a calmer period begins and the beach starts recovering.

At the end of June 2000 a beach nourishment was applied between Y = 0 m and Y = 800 m. As a result the intertidal beach is extended in that area which is clearly visible in the plot of July 2000. During the first month after the completion of the beach nourishment, carried out at the end of June 2000 between Y = 0 m and Y = 800 m, a lot of the nourished sand has already disappeared out of the intertidal beach profile, especially near Y = 700 m. The next two months till October 2000 the intertidal beach doesn’t change much as a result of the calm weather conditions. Then the stormy season sets in and the intertidal beach retreats at all locations, up to approximately 30 m in November 2000. In December 2000 the extended beach, between Y = -600 m and Y = 0 m, is flattened out.

Then in January 2001 a large amount of sand has settled on the intertidal beach between Y = -1000 m and Y = 0 m. The origin of this sand suddenly entering the intertidal beach is not clear. In March 2001 the beach recovery begins as a result of the calmer weather conditions and continues until August 2001. In this period mostly the area between Y = -1000 m and Y = 0 m shows progression of the beach while the location of the beach between Y = 0 m and Y = 1000 m is unchanged. In September 2001 erosion can be noticed again at all longshore locations.
4.4 Quantification of the intertidal beach

This section discusses features of the intertidal beach like volume changes and beach width. These features can be derived on a monthly basis from the collected intertidal beach profiles and give a good impression about the changing morphology of the intertidal beach. Section 4.5 discusses the bar dynamics in front of the Egmond beach. Results are showed in Appendix F. Each of the figures in Appendix F consists of 4 plots. The plots respectively show beach width, volume changes, wave heights and bar dynamics.

4.4.1 Approach

To analyse beach width and volume changes of the intertidal beach on a monthly basis, the area is divided into 9 equally spaced sections. The width of each section is 200 m, together covering a stretch of beach 1800 m long (Figure 4.9). However, this area is not completely covered by the Caljouw profiles. With the old IBM version it was not possible to map shorelines further away from the camera than 700 m. Hence for the period June 1999 – June 2000, only for sections 2 – 8 (together 1400 m) volume changes can be computed.

The part of the beach between MLW and MHW is called the intertidal beach. Hence the tidal range determines the extension of the intertidal beach. At Egmond the mean tidal range is 1.65 m. However it was not possible to cover this range for all collected intertidal beach profiles. Therefore all beach profiles are set to a smaller range. All z-coordinates larger than NAP +1.0 m are set to NAP +1.0 m and all z-coordinates lower than NAP -0.4 m are set to NAP -0.4 m. For all sections beach width and volume changes are derived separately.

4.4.2 Volume changes

The Caljouw dataset of beach profiles covers a range of only 1.0 m (NAP +0.0 m – NAP +1.0 m) while the new dataset covers a range of 1.4 m (NAP -0.4 m – NAP +1.0 m). To be able to compare volume changes of the Caljouw dataset with the new dataset the tidal range should be the same for both datasets. Therefore, all volume changes of the new dataset are divided by the range of the beach profiles resulting in volume per m (longshore direction) per m (vertical sense). For every section the results are plotted in Appendix F.
Error in calculated volume changes

Monthly volume changes are derived by subtracting the intertidal beach profiles of successive months. Since errors can be found in the intertidal beach profiles there will be errors in the calculated volume changes.

However, distinction has to be made between systematic and random errors to define the mean error in the volume changes. Systematic errors are irrelevant as they do not have any effect on the calculated volume changes, only random errors do. Therefore the standard deviation of the intertidal beach profiles has to be taken into account when calculating the volume changes.

Section 4.2 describes the validation of the intertidal beach mapping. Validation was carried out for the model itself by comparing mapped shorelines with measured shorelines and also for the interpolated beach profiles. The standard deviations for both cases are in the order of 0.20 m in vertical sense. This corresponds with a horizontal deviation of 8 m, assuming a mean beach slope of 1:40. The mean error in the calculated volume changes per m alongshore per m in vertical sense yields 8 m$^3$.

Description of results

Generally, all sections show erosion between September 1999 and February 2000 and between October 2000 and December 2000, due to the stormy weather conditions in these periods. However a direct relation between weather conditions and erosion or accretion of the intertidal beach can not be noticed. For example, a stormy weather period does not result in erosion for each section, some even show accretion. During calm weather conditions some sections even show much erosion which is unexpected. This must be the result of exchange of sand between adjacent sections which indicates complex 3-Dimensional physical processes including the migration of nourishments.

For the sections 2 to 5 the increase of sand in the intertidal beach as a result of the beach nourishment is clearly visible. The increase in sand volume amounts about 60 – 70 m$^3$/m/m. Note that the volume of the beach nourishment applied yields 258 m$^3$/m (Table 2.1). Thus, about 25% of the nourished sand has settled in the area bounded by the tidal range. Probably most of the nourished sand has settled in the area above NAP +1.0 m. However a lot of the nourished sand has left the area already the next month, especially for section 2.

4.4.3 Beach width

Just as waves can contribute to a sediment movement along a coast (longshore transport), they can also contribute to the cross-shore transport of sediment. Typical examples of this wave-induced sediment movement are the well-known summer and winter beach profiles. Beach profiles can generally be classified into two basic types, summer profiles or winter profiles.
In the winter the mean wave conditions are more intense than in summer. Material is moved offshore, the intertidal beach slope becomes steeper and beach width decreases. In summer the mean wave height decreases, beach recovery begins. Sand is transported onshore, the slope of the intertidal beach becomes gentler and beach width increases.

Beach width is defined as the area between the dune foot and the shoreline. Maintaining sufficient beach width is important for recreation. Especially in the summer months it is important to have enough space between the dune foot and the high tide shoreline. Apart from this, beach width indicates to a certain extent the risks of flooding.

In order to determine beach width, the position of the dune foot has to be known. The dune foot position is defined as the NAP +3 m elevation line of the beach. Every two years the present position of the dune foot is determined with respect to the RSP line. RSP stands for ‘Rijks Strand Paal’, indicating beach poles which have been placed every 250 m along the Dutch coast. This means that the position of the dune foot is expressed in a distance measured from these beach poles. After the position of the dune foot is known, beach width can be determined (Figure 4.11).

To analyse the variation in beach width in time, the area of interest is again divided into 9 equally spaced sections (Figure 4.9), each 200 m wide. For every section mean beach width is determined at MHW and MLW. Results are plotted in Appendix F. The distance between the MHW-line and MLW-line indicates the slope of the intertidal beach.

The figures show much variation in beach width both in time and in space. A lot of variation can also be noticed in the slope of the intertidal beach. Generally during the winter months most sections show a steeper beach slope while during the summer months the beach slope becomes gentler. However this is not consistent for all sections throughout the observed period. Probably, this can mostly be contributed to the way in which the position of the MLW-line is determined. Since the range of the mapped beach profiles is limited to NAP +1.0 m and NAP -0.4 m the MLW-line (NAP -0.76 m) is determined by extrapolation. A mean slope of the intertidal beach is computed and extrapolated to the MLW-line. However the beach slope below NAP -0.4 m is often less steep than above NAP -0.4 m. This means that for some cases the real position of the MLW-line is located more seaward than is computed by extrapolation.

The intertidal beach at section 2 and 3, corresponding with the area Y = 700 m to Y = 300 m, has almost reached the dune foot in the spring of 2000. The effect of the nourishment can be seen clearly in the beach width of the sections 2, 3 and 4. As a result beach width increased with 60 m. The next month beach width has decreased with 20 m while after the stormy conditions at the end of October the MHW and MLW have moved even 40 m farther landward. From then till August 2001 the position of the MHW stays rather stable. However in September 2001 the MHW seems
to start moving towards the dunefoot again which may indicate the start of an erosional trend.

For the sections 6, 7 and 8 the width of the dry beach is consistent over the observed period of 28 months. Some increase in beachwidth occurs during the calm summer months while some decrease can be noticed during the stormy winter months.

4.5 Bar behaviour

Argus Merge Tool

In order to analyse the behaviour of the bars in the surfzone at Egmond, merged images have been collected for the period between June 1999 and September 2001. Only images are used at the moments wave heights are bigger than 1.5 m. When possible, the images are collected with one month intervals, see Appendix H.

In the merged images of June and July 1999 the three bar system at Egmond is clearly visible. The straight outer bar is located at $X = 500$ m. Southward of $Y = 0$ m less dissipation can be found above the outer bar crest indicating a shallower bar crest level northward of $Y = 0$ m. The crest of the inner bar has an irregular alongshore planview located at around $X = 200$ m. The swashbar follows more or less the shape of the intertidal beach.

Soon after the completion of the shoreface nourishment at the end of June 1999, the outer bar starts moving in onshore direction. This migration of the outer bar continues until September 2000 when it has moved more than 100 m in onshore direction. However the part of the outer bar southward of $Y = 1000$ m remains stable. In November 1999 the part of the inner bar around $Y = -150$ m starts moving in offshore direction and curling around the extension of the beach at that location. Until October 2000 this pattern of the bars stays unchanged. The trough between the inner bar and the swash bar has become very small and at some locations the bars seem to be connected to each other.

In November 2000 the inner and outer bar northward of $Y = 0$ m move even farther towards the beach. Southward of $Y = 0$ m the bars, including the swashbar, move in onshore direction and a new swashbar is being created. This change causes the inner bar to break loose at $Y = 0$ m. In the merged image of December 2000 it can be seen that the (former) inner bar southward of $Y = 0$ m has become the new inner bar and is attached to the outer bar northward of $Y = 0$ m. The former swashbar southward of $Y = 0$ m has become very small and at some locations the bars seem to be connected to each other.

In November 2000 the inner and outer bar northward of $Y = 0$ m move even farther towards the beach. Southward of $Y = 0$ m the bars, including the swashbar, move in onshore direction and a new swashbar is being created. This change causes the inner bar to break loose at $Y = 0$ m. In the merged image of December 2000 it can be seen that the (former) inner bar southward of $Y = 0$ m has become the new inner bar and is attached to the outer bar northward of $Y = 0$ m. The former swashbar southward of $Y = 0$ m has become the new inner bar and is attached to the outer bar northward of $Y = 0$ m. The outer bar southward of $Y = 1000$ m is now attached to the shoreface nourishment which now functions as the outer bar. During the spring and summer of 2001 the new inner bar is irregular shaped. However in September 2001 the inner bar has become straight. Maybe a new equilibrium has been reached.

Argus Stack Tool

Bar behaviour is also analysed by using the Argus stack tool. For every section (Figure 4.9) a stacked image was composed along a stack located in the middle of the specific section, perpendicular to the coastline. Results can be found in appendix F.

In the stacked images of sections 5 to 9 (northwards of $Y = 0$ m) the outer bar and the inner bar are pronounced by the white bands while the swashbar is just vaguely visible. In contrary, southward of $Y = 0$ m (sections 1 to 4) the outer bar is not visible while the swashbar is well pronounced. This may indicate that the outer bar crest between $Y = 800$ m and $Y = 200$ m is lower than northward of $Y = 0$ m. Consequently less wave energy is dissipated on the outer bar and more energy is left over to dissipate on the inner bar and swash bar.
4.6 Conclusions

Argus Tools

With the renewed version of IBM it is possible to map shorelines further away from the camera. With the possibility to adapt the region of interest manually, shorelines can also be mapped for less optimal image quality conditions. The mean deviation of the overall model varies between 0.1 m close to the camera and 0.3 m far away from the camera in vertical sense. Standard deviations are approximately 0.2 m.

The Loess interpolation method performs better on interpolating the mapped shorelines to beach profiles than a simple linear interpolation method. Although no improvement is found in the mean deviations the Loess interpolation method shows more consistency than the linear interpolation method.

The Argus Merge Tool is a very powerful tool to analyse the behaviour of bars in the nearshore zone. Studying merged images, taken at moments wave heights are bigger than 1.5 m, give a good impression about the movement of the bars.

Observed morphologic changes

The intertidal beach profiles gathered on a monthly basis, over the period of June 1999 to September 2001, give a good impression about the appearance of the intertidal beach. Generally erosion can be found at all longshore locations during the stormy winter months and accretion during the calm summer months.

At Y = -250 m the beach is extended in offshore direction while at Y = 500 m the beach is retreated. This typical shape of the intertidal beach is almost unchanged throughout the observed period. The beach nourishment of June 2000 is clearly visible in the contourplot of July 2000. However the nourishment is not adopted by the system. Only four months later most of the nourished sand has disappeared out of the intertidal beach and the beach seems to change back to the typical shape it had before the intervention. In the summer of 2001 the intertidal beach is almost equally shaped as it was before the intervention.

Analysing the volume changes of the separate sections indicate that a lot of sand exchanges takes place between the adjacent sections. This may indicate that complex 3-Dimensional physical processes dominate the intertidal beach area.

Much variation in beach width both in time and in space can be noticed. However, northward of Y = 0 m (sections 6, 7, 8 and 9) the width of the dry beach is consistent over the observed period of 28 months. Some increase in beachwidth occurs during the calm summer months while some decrease can be noticed during the stormy winter months.

The effect of the beach nourishment applied at the end of June 2000, can be seen clearly in the beach width of the sections 2, 3 and 4 (Y = 150 m to Y = 600). As a result beach width increased with 60 m. However, only four months later the intertidal beach has moved over approximately 50 m in onshore direction again. From then till the summer of 2001 beach width stays rather stable.

A lot of variation can also be noticed in the slope of the intertidal beach. Generally during the winter months most sections show a steeper beach slope while during the summer months the beach slope becomes gentler.

Merged images show less wave breaking, indicating a depression in the outer bar crest elevation, between Y = 200 m and Y = 1000 m. Besides this, wave breaking over the shoreface nourishment seems to be a bit less southward of Y = 0 m than northward of Y = 0 m, suggesting a lower crest
The shoreface nourishment disturbs the equilibrium. After the accomplishment of the shoreface nourishment in summer 1999 the outer bar between Y = 1000 m and Y = -1000 m starts moving in onshore direction, fastest at Y = -150 m and the system starts searching for a new equilibrium. In November 2000 the inner bar southward of Y = 0 m has broken lose from the inner bar northward of Y = 0 m and has moved in offshore direction. The outer bar between Y = 0 m and Y = 1000 m has almost decayed then. In December 2000 the inner bar southward of Y = 0 m is attached to the outer bar northward of Y = 0 m. The outer bar southward of Y = 1000 m has attached to the shoreface nourishment. The ‘attachment-points’ at the new inner bar are still visible in the following months around Y = 450 m and Y = -1000 m.
5 The Egmond Model

5.1 Introduction

In this chapter the numerical model Delft3D is used to analyse the effect of the shoreface nourishment on the physical processes in the nearshore zone. The Delft3D system is a process-based modelling system capable of simulating:

- flows due to tide, wind, density gradients and wave induced currents;
- propagation of directionally spread short waves over uneven bathymetries, including wave-current interaction;
- advection and dispersion of effluents;
- sediment transport of cohesive and non-cohesive sediment;
- water quality phenomena;
- particle tracking;
- initial and/or dynamic (time varying) 2D-morphological changes, including the effects of waves on sediment stirring and bed-load transport.

Delft3D is composed of a number of modules, each addressing a specific domain of interest, such as flow, wave generation and propagation, morphology and sediment transport. Detailed information about each of these models can be found in the Delft3D user manuals.

5.2 Set up of Egmond model

5.2.1 Flow model

Computational grid

The computational grid of the Egmond model used by Delft3D-FLOW was constructed with the program RGFGRID. It covers an area 2300 m wide and 10400 m long with the shoreface nourishment located at the centre. The model area is much larger than the area of interest, in order to avoid boundary disturbances in the area of interest.

To save computational time the grid size varies over the model grid. At the area of interest, where the shoreface nourishment is located, the grid size is chosen at 20 x 40 m², whereas the grid size near the boundaries is about 100 x 400 m². In this way detailed information can be obtained in the area of interest while outside this area the computational grid is coarser.

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<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</tr>
<tr>
<td>Number of cells in M-direction</td>
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</tr>
<tr>
<td>Number of cells in N-direction</td>
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<tr>
<td>Minimum grid distance</td>
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<tr>
<td>Rotation</td>
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Table 5.1 FLOW grid specifications
Bottom topography

With the help of the program QUICKIN a bottom depth is assigned to every grid cell. A bathymetry data set of 01-09-1999 is used for generating the bottom file of the Egmond model. However this data set is incomplete to cover the entire computational grid. Since the missing part of the September data set is not situated in the area of interest it is extended with a data set of May 1999.

The bathymetry data sets are loaded into the program QUICKIN and by means of triangular interpolation interpolated to the computational grid of the Egmond model. The bottom topography of the Egmond model is shown in Appendix L.

Boundary conditions

In Delft3D-FLOW the transitions between dry land and water are represented by closed boundaries. This means that flow velocities perpendicular to these boundaries equal 0. Along the open boundaries of the model water level boundaries are specified to simulate the tidal cycle present at Egmond.

Simulating a complete tidal cycle over the modelled morphological time would lead to very high computational effort. To save computational time a tidal schematisation has to be made. Van Duin (2002) made a tidal schematisation of the Egmond model which will be used in this study.

The Egmond model was first nested in a Northsea model, which covers the Dutch coast of North and South Holland and part of the Wadden Islands. This resulted in time series of waterlevels and currents at the Egmond model boundaries. Then, in order to find the harmonical components of the morphological tide a Fourier analysis was performed with the waterlevel time series. This resulted in the schematised tidal components shown in Table 5.2 and Table 5.3 which are set up in Delft3D-FLOW.

<table>
<thead>
<tr>
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<th>Frequency</th>
<th>Amplitude (cm)</th>
<th>Phase</th>
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<tr>
<td>12</td>
<td>172.8</td>
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<td>141.0</td>
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</table>

Table 5.2 Schematised morphological components point A

<table>
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<th>Phase</th>
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<tr>
<td>12</td>
<td>172.8</td>
<td>1.7</td>
<td>128.1</td>
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</tbody>
</table>

Table 5.3 Schematised morphological components point B
Point C, located in the centre of the model, is defined as an observation point in the Delft3D model. Waterlevels and currents in this point due to the schematised morphological tide are shown in Figure 5.1. Current $u$ is the current in cross-shore direction, current $v$ is the current in longshore direction.

![Figure 5.1 Waterlevel and currents in point C](image)

5.2.2 WAVE model

To simulate the evolution of wind-generated waves in coastal waters the Delft3D-WAVE module can be used. The module computes wave parameters from given bottom, wind and current conditions. At present two wave models are available in Delft3D. They are the second-generation HISWA wave model (Holthuijsen et al., 1989) and, its successor, the third-generation SWAM wave model (Booij et al., 1999; Ris et al., 1999).

The great advantage of SWAN, compared to HISWA, is that the physics are explicitly represented with state-of-the-art formulations and that the model is unconditionally stable, whereas Hiswa uses highly parameterised formulations for the physical formulations. Moreover, the SWAN model can perform computations on a curvilinear grid which results in better coupling with the FLOW module of Delft3D. In addition, the wave forces, as computed by SWAN on the basis of the gradient of the radiation stress tensor, can be used as driving force to compute the wave-induced currents and set-up in the FLOW module. Regarding these advantages of the SWAN model with respect to the HISWA model, the SWAN model is used to simulate waves in the Egmond model.

Background information about the SWAN model can be found in the Delft3D-WAVE user manual.

In order to model wave conditions which are representative for the Egmond site, the results of a wave schematisation made by Van Duin (2002) is used. Van Duin made this schematisation to do a hindcast with Delft3D of the Egmond site with a reliable description of the net transports. The reason to make a schematisation is to save computational time since modelling of a complete wave climate would take a lot of computational effort.
The Unibest (UNiform BEach Sediment Transport) program was used for the schematisation of the morphological wave climate. The schematisation is based on the condition that the schematised net transport in Unibest has to be equal to the net transport in Unibest using the hydronamic time series. Wave time series measured at IJmuiden for the period September 1999 to May 2000 have been used and resulted in twelve wave conditions: six wave directions with each two wave heights (Table 5.4).

<table>
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<td>345</td>
<td>2.25</td>
<td>8.7</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 5.4  Schematised wave conditions

Some of these conditions are used in this study as representative wave conditions for the Egmond model, reference is made to section 5.3.

### 5.2.3 TRANSPORT and BOTTOM module

The TRANSPORT model determines the sediment transport using time-dependent flow and effects of a wave field. The sediment transport module computes the bed-load and suspended-load sediment transport field over the curvi-linear FLOW grid, for a given period of time.

The bed-load and suspended-load transport can be modelled by a range of formulations, among which are Engelund-Hansen, Meyer-Peter-Muller, Bijker, Bailard and Van Rijn. The Bijker formula was used in this study since this was the only model available which included both transport by currents and transport by waves.

In the model BOTTOM the bed-level variations due to gradients in the sediment transports are computed. The bottom update model contains several explicit schemes of Lax-Wendroff type for updating the bathymetry based on the sediment transport field.

More detailed information about the TRANSPORT and BOTTOM module can be found in the Delft3D-MOR user manual.
5.3 Simulations

5.3.1 Introduction

In this section the simulations made with the Egmond model are discussed. With these simulations it is tried to gain more insight in the effect of the shoreface nourishment on the morphology at Egmond. Currents, wave dissipation, wave setup and sediment transport are studied for several different wave conditions.

5.3.2 Adapted bathymetry

In order to gain more insight in the effect of the shoreface nourishment on the physical processes at the Egmond nearshore zone, basically three different runs are set up. For each run the bathymetry is adapted manually in QUICKIN to:

- **Run A** - the shoreface nourishment is removed out of the bathymetry.
- **Run B** - the crest of the shoreface nourishment is adapted to a level of NAP -5.5 m over the full length of the shoreface nourishment, hereafter referred to as symmetric shoreface nourishment.
- **Run C** - the northern half of the shoreface nourishment is adapted to a crest level of NAP -5.0 m, the southern half is adapted to a declining crest level varying linearly from NAP -5.0 m to NAP -6.0 m, hereafter referred to as asymmetric shoreface nourishment.

Comparing the results of a run with shoreface nourishment and a run without shoreface nourishment, provides insight in the effect of the shoreface nourishment on the physical processes in the nearshore zone.

The merged images which are studied in section 4.5 may indicate that the crest of the shoreface nourishment has a small decline. The crest of the northern part of the shoreface nourishment seems to be higher than the southern part. Therefore a bathymetry with a symmetric shoreface nourishment and a bathymetry with an asymmetric shoreface nourishment is chosen. This makes it possible to analyse the effect of a shoreface nourishment which is not equally high.

The choice to adapt the crest elevation of the shoreface nourishment to a level of NAP -5.5 m in case of run B, is based on the bathymetry data of September 1999 (Table 2.2). This data shows that the crest elevation varies around NAP -5.5 m. It also confirms that the crest elevation is somewhat lower over the southern half of the shoreface nourishment and higher on the northern half of the shoreface nourishment.

5.3.3 Simulations

Every run is carried out for several wave conditions. In Table 5.5 the wave conditions for each run are given. For every run a condition with a high wave coming from the northwest and a condition with a high wave coming from the southwest is simulated. For run B a simulation with a low wave condition coming from north-western and south-western direction has been done.
Table 5.5 Simulations

5.4 Description of results

5.4.1 Flow velocities

Flow velocities of run A, B and C are plotted in figures 1 (A.1, B.1 and C.1) for high waves coming in from north-western direction and in figures 2 (A.2, B.2 and C.2) for high waves coming in from south-western direction.

The flow direction landwards of the outer bar is dominated by the wave direction. Conditions with waves coming in from north-western direction give a southward flowing current, waves coming in from south-western direction give a northward flowing current. At deeper water the flow direction is dominated by the tidal current. During flood, water is flowing northward while during ebb the flow is directed to the south.

Due to the opposite directed flow currents nearshore and further offshore during certain periods in the tidal cycle, large current circulations (in the order of 500 to 800 m) are initiated. These circulations occur between 500 and 1000 m offshore. With the northwest high wave condition these circulations can be noticed during large flood currents (High water, Maximum flood) and are rotating clockwise. In case of the southwest high wave condition these circulations are only clearly visible during maximum ebb currents and are rotating counter clockwise. These circulations are created by a flow current directed offshore which is much more pronounced than the onshore directed flow current within that circulation cell.

When looking at the flow velocity figures of run A, B and C, for both northwest high wave condition and southwest high wave condition very little difference neither in current direction nor in current velocity can be found.

In case of the low wave conditions (figures B.8 and B.9) the area landwards of the inner bar is dominated by the wave direction. Further offshore the flow currents changes sign with flood and ebb period. With the southwest low wave condition circulation currents (in the order of 200 to 300 m) are initiated during maximum ebb velocities resulting in relatively strong currents passing the inner bar. Besides this during low water irregular flow patterns can be noticed making water entering and leaving the inner trough at lower inner bar crest locations with waves coming in from both north-western and south-western direction.
5.4.2 Wave dissipation

Figures 3 (A.3, B.3 and C.3) of run A, B and C show wave dissipation for northwest high and southwest high wave conditions at high water and low water. High dissipation is clearly visible at the outer and inner bar and in case of run B and C at the shoreface nourishment. During high water high rates of dissipation can also be found at the swash bar. Dissipation during low water is higher at the outer bar than out the inner bar.

The plots with southwest wave conditions show less wave dissipation than the plots with northwest wave conditions. This is due to the angle of the waves entering the nearshore zone. The angle of the waves coming in from the northwest is about 15° more toward the shore-normal than the waves coming in from the southwest.

In case of the simulations with a shoreface nourishment (run B and C) wave energy is dissipated at the shoreface nourishment, especially during low water periods. Compared to the simulations without shoreface nourishment, less energy is dissipated on the outer bar. However the dissipation rate at the inner bar stays almost unchanged.

The difference in wave dissipation between the symmetric and asymmetric nourishment is only visible at the outer bar and during low water periods. More wave energy is dissipated on the shallower northern side than on the deeper southern side of the asymmetric shoreface nourishment.

Figure B.9 shows the wave dissipation in case of low wave conditions. Most of the wave energy is dissipated at the inner bar during low water periods while during high water periods most of the dissipation can be found at the swashbar.

5.4.3 Wave setup

Wave setup patterns are shown in figures 4 (A.4, B.4 and C.4) of run A, B and C for high waves coming in from north-western direction and in figures 5 (A.5, B.5 and C.5) for high waves coming in from south-western direction.

For northwest high wave conditions the wave setup in the outer trough is about 6 cm at high water periods and about 2 to 4 cm during low water periods. The wave setup in the inner trough varies between 15 cm at high water and 8 cm at low water. At the swash zone even larger wave setups occur. For southwest high wave conditions wave setup is a few centimetres smaller than in case of the northwest wave condition.

The difference in wave setup between simulations without shoreface nourishment and with shoreface nourishment can mainly be observed right behind the shoreface nourishment. In case of the simulation with shoreface nourishment the wave setup is larger in that area during low water periods. For a detailed study of the wave setup differences between the several simulations difference plots of wave setup should be made.

5.4.4 Tide-averaged transport

Figures 6 (A.6, B.6 and C.6) show the tide-averaged transport for high waves coming in from north-western direction and south-western direction. Just as the flow direction, the tide-averaged transport is dominated by the wave direction in the nearshore zone. Northwest wave conditions give a southward directed transport, southwest wave conditions cause a northward directed transport. Large transports can be found at shallower locations like the inner bar, outer bar and shoreface nourishment where the flow velocities are strongest.
In figures D.1 and D.2 the total transports of the simulation without shoreface nourishment is subtracted from the total transports of the simulation with (symmetric) shoreface nourishment. This results in difference plots. The direction of the total transport depends for all simulations on the incoming wave direction. This means that arrows in the difference plots, pointing in opposite direction of the wave dominated transport direction, indicate a larger transport in case of the simulation without shoreface nourishment. Arrows pointing in the same direction as the wave dominated transport direction indicate a larger transport in case of the simulation with shoreface nourishment.

Figures D.3 and D.4 show difference plots of the total transports in case of a symmetric shoreface nourishment and an asymmetric nourishment. The total transports of the simulation with the asymmetric shoreface nourishment is subtracted from the total transports of the simulation with a symmetric shoreface nourishment. The plots have to be interpreted in the same way as figures D.1 and D.2.
6 Evaluation of morphologic changes at Egmond

6.1 Introduction

Morphological development of the intertidal beach and the nearshore zone is analysed with the help of Argus video techniques over a period of more than 2 years. Physical processes in the nearshore zone at Egmond have been simulated with Delft3D. In this chapter an evaluation of the morphologic changes at Egmond is presented.

6.2 Long term coastline development

The coastline of North Holland has undergone large changes in the past thousand years. Especially the coast northward of the Hondsbossche Sea defence has been suffering a large retreat. Between 1665 and 1940 the coastline moved landward over 250 m. Also at Egmond serious regression of the coastline has occurred.

Measurements of shorelines indicate that the retreat of the coastline near Egmond has been stopped since 1843. Generally, northwards of Egmond some retreat of the coastline is still occurring while southwards of Egmond progress of the coastline can be noticed.

Boers (1999) studied the tendency of the North Holland coastline. Shoreline positions (Dune foot, MHW, MLW) available since 1843 and JARKUS measurements available since 1964, were used for this study. Figure 6.1 shows the mean velocity of the displacement of the dune foot, MHW and MLW between 1843 and 1983. Around Egmond the mean annual displacement of the dune foot, MHW and MLW is small. The coastline can be considered as stable.

It is assumed that the (wave driven) longshore transport flattens out inequalities off the coastline. This is probably also the reason for the short lifetime of the beach nourishments at Egmond.

Boers also showed that the difference between the mean width of the dry and wet beach at Egmond over the period 1964 – 1989, and the mean beach width of the adjacent coastal areas is negligible over the period of 1964 to 1989. However, a serious variation in beach width can be noticed in time. Figure 6.2 shows the width of the dry beach at Egmond between 1964 and 1998. The beach width varies between 20 and 60 m in short periods of time. In space, considerable variations in beach width can be found also over relatively small alongshore distances. It is quite
obvious that at certain moments beachwidth does not satisfy to the demand the recreational sector is asking for. This is caused by natural fluctuations, which are part of the system and since 1990 also by the applied nourishments, which can significantly increase beach width.

However measuring beach width at different time points each year, also contribute to the variations in beach width in Figure 6.2. These short scale variations in beach width both in time and space were also noticed with the Argus monitoring techniques.

6.3 Observed coastline development at Egmond

Historical data of the coastline show that short scale changes in beachwidth both in time and in space can be noticed at Egmond. Studying the intertidal beach at Egmond with the help of the Argus tools also showed this development of short scale features. In summer months extension of the beach can be found at all longshore locations. During the stormy winter months erosion of the beach can be noticed and the beach retreats at all longshore locations.

However the shape of the intertidal beach at Egmond stays almost the same. At RSP 37.75 (Y = -250 m) the beach is extended in onshore direction while at RSP 38.50 (Y = 500 m) the beach is retreated. There seems to be a system which controls the general morphological development of the intertidal beach.

Even the artificial intervention by means of the beach nourishment in June 2000 seems not to be adopted by the system. A lot of the nourished sand has left the intertidal beach already the next month and four months later in November 2000 the intertidal beach has almost changed into the shape it had before the intervention.

Analysing the merged images shows that the outer bar crest elevation shows a depression between RSP 39.00 (Y = 1000 m) and RSP 38.00 (Y = 0 m). Furthermore the shoreface nourishment seems to have a slightly declined crest level southward of Y = 0 m. This is illustrated in Figure 6.3. Waves coming in from a certain direction will dissipate less on the lower crested shoreface nourishment and outer bar. More energy is left at those locations to enter the inner nearshore zone. The beach southward of Y = 0 m is therefore less protected against the incoming waves. More sediment will be stirred up and transported in longshore direction by the wave-driven longshore currents. Northward of Y = 0 m the shallower shoreface nourishment and outer bar create a lee area and protect the beach from wave attack. In the lee area the sediment can settle down as a result of the calmer wave conditions at that location. As can be seen in Figure 6.3 accretion takes place between RSP 37.00 and RSP 38.00 while erosion can be found between RSP 38.00 and RSP 39.00. This pattern of erosion and accretion may cause the typical shape of the intertidal beach.

![Figure 6.2 Width of dry beach between 1964 and 1998](image_url)
Besides the longshore transport, cross-shore transport can also contribute to erosion or accretion of the beach. Transport of sediment takes place by time-mean seaward directed flow near the bottom, induced by the breaking of waves (undertow). It is expected that more wave breaking at the inner nearshore zone can be found between RSP 38.00 and RSP 39.00 and less wave breaking between RSP 37.00 and RSP RSP 38.00. Consequently more offshore directed transport will occur between RSP 38.00 and RSP 39.00 and less offshore directed transport between RSP 37.00 and RSP 38.00. This (alongshore) variation in cross-shore transport may also contribute to the typical shape of the intertidal beach.

6.4 Longshore transport

Tide-averaged total transports are computed with the Delft3D Egmond model for several wave conditions and different bathymetries.

When studying erosion and accretion caused by longshore transport the amount of sediment transported is irrelevant. Only gradients in the longshore transport cause erosion or accretion. To study erosion and accretion caused by longshore transport, the total tide-averaged transport in the inner nearshore zone is computed. The inner nearshore zone is defined as the area between the inner bar and the intertidal beach.

Appendix J shows plots of the tide-averaged longshore transport in the inner nearshore zone for the several wave conditions and bathymetries which were simulated in the Delft3D model. The upper plots show the longshore transport and the lower plots show the gradients in the longshore transport. According to the Argus system of axes, transports directed to the north are presented as negative values, transports directed to the south are presented as positive values. As a result, for both northwest and southwest directed transports, positive values of the gradients indicate erosion while negative values of the gradients indicate accretion.

When looking at the longshore transport rates with high wave conditions for the simulations with different bathymetries, very little differences can be noticed in the longshore transport and the longshore transport gradient. The presence of the shoreface nourishment seems to have no effect on the longshore transport in the inner nearshore zone.

Figure 6.4 shows the longshore transport in case of the low wave conditions with shoreface nourishment. The longshore transport rates are approximately 10 times lower than in case of the high wave conditions. However very remarkable, gradients in the longshore transport are about twice as large. Since only gradients in the longshore transport do account for accretion or erosion most accretion and erosion do occur during low wave conditions.
Although no simulations with low waves were done for a bathymetry without shoreface nourishment, it is expected these simulations would give approximately the same transport rates and gradients. During low wave conditions no wave breaking can be found at the shoreface nourishment (Figure B.9, Appendix L) and therefore the situation is expected to be similar to a simulation without shoreface nourishment.

The prevailing wave direction at the Holland coast is southwest. Between $Y = 400$ m and $Y = 1000$ m and between $Y = -800$ m and $Y = -500$ m erosion can be seen in case of the southwest wave condition (Figure 6.4). Between $Y = -500$ m and $Y = 400$ m accretion takes place. This pattern of erosion and accretion along the shore is very similar to the shape of the collected intertidal beach profiles. In case of the north-western wave condition the same erosion and accretion pattern can be noticed, although shifted a little southward.

The reason for the higher rate of erosion and accretion during a low wave condition compared to a high wave condition may be found in the strength of the longshore current. During high wave conditions the longshore current is too strong to develop large gradients in the longshore transport (J.C. van Noort, 1997).

### 6.5 Effect of shoreface nourishment

On the decadal time scale bars often show a migrational cycle in offshore direction with decay of the outer bar at the edge of the surf zone and generation of a new bar at the foot of the beach (Wijnberg, 1995). The typical cycle time of the bars at Egmond is about 15 years. After the completion of the shoreface nourishment however this offshore moving trend of the bars is completely disturbed. The outer bar has shifted 200 m in onshore direction within a period of only one year. This might be due to the fact that a lot of sand is added to the area and the system starts searching for a new equilibrium.

If wave conditions vary along a coast, then wave set-up will also vary along the coast. The variation in wave conditions along the coast can be caused be refraction and diffraction but also by differences in breaker type like coastal slope variations. The water level differences along the coast will obviously produce pressure gradients along the coast. These pressure gradients can contribute importantly to the driving force for the longshore current at locations where the wave
conditions vary rapidly along the beach (Bakker 1971).

The effect of the shoreface nourishment on the physical processes in the nearshore zone is analysed with Delft3D. Tide-averaged transports are computed and plotted in Figures A.6, B.6 and C.6 of Appendix L for the three simulations respectively. In figure D.1 and D.2 (Appendix L) residual transports are shown after subtracting total tide averaged transports of the simulation without shoreface nourishment from total tide averaged transport of the simulation with shoreface nourishment.

For the northwest wave condition (tide-averaged transports are directed southwards) transports right behind the shoreface nourishment are smaller than without a shoreface nourishment while at the shoreface nourishment they are larger. This is expected. However, the southward directed transports in the inner nearshore zone northward of $Y = 0\,\text{m}$ have increased as a result of the shoreface nourishment. Southward of $Y = 0\,\text{m}$ the southward directed transports have decreased (Figure 6.5a). This may indicate an onset for a large net circulation as illustrated in the figure.

In case of the southwest wave condition (figure D.2) this can not be noticed. The tide averaged transports behind the shoreface nourishment and in the inner nearshore zone have decreased as a result of the shoreface nourishment.

In figures D.3 and D.4 the residual transports, after subtracting total tide averaged transports of the simulation with the symmetric shoreface nourishment from the simulation with the asymmetric shoreface nourishment, are plotted. Figure 6.6 shows schematically the residual transports for northwest and southwest wave condition. Again in case of the northwest wave condition there may be an onset for large net circulations.

The differences in tide-averaged transports for the different bathymetries indicate the presence of large net circulations.
6.6 Historical nourishments at Egmond

Experience shows that beach nourishments at the Egmond coast have a relatively short lifetime of about 1 to 2 years. Appendix K shows beach volumes between 1964 and 2000 of transects taken every 250 m alongshore. The volumes concern the area between NAP -0.8 m and NAP +3 m contours. This is the area where the nourishments, which generally have a volume between 100 and 200 m$^3$/m, are placed. This area actually includes the intertidal beach and the swashbar.

The volumes show much variation in both time and space. Since 1990 several beach nourishments have been applied at Egmond, an overview can be found in Table 6.1. Volumes added as a result of nourishments disappear relatively fast, often in a time span of 1 or 2 years, as can be seen in the beach volume plots. The beach nourishments do not seem to contribute to a long term increased volume of the beach.

<table>
<thead>
<tr>
<th>Start of suppletion</th>
<th>Begin transect</th>
<th>End transect</th>
<th>Volume</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 1990</td>
<td>37.00</td>
<td>38.50</td>
<td>385000</td>
<td>2</td>
</tr>
<tr>
<td>June 1992</td>
<td>26.20</td>
<td>38.50</td>
<td>1473000</td>
<td>2</td>
</tr>
<tr>
<td>September 1992</td>
<td>37.65</td>
<td>38.20</td>
<td>106000</td>
<td>2</td>
</tr>
<tr>
<td>June 1994</td>
<td>37.85</td>
<td>38.75</td>
<td>306000</td>
<td>2</td>
</tr>
<tr>
<td>April 1995</td>
<td>37.25</td>
<td>38.75</td>
<td>314000</td>
<td>2</td>
</tr>
<tr>
<td>May 1997</td>
<td>36.25</td>
<td>38.80</td>
<td>244000</td>
<td>2</td>
</tr>
<tr>
<td>June 1998</td>
<td>37.50</td>
<td>38.75</td>
<td>215000</td>
<td>2</td>
</tr>
<tr>
<td>April 1999</td>
<td>37.25</td>
<td>39.10</td>
<td>888000</td>
<td>3</td>
</tr>
<tr>
<td>June 2000</td>
<td>38.00</td>
<td>38.80</td>
<td>207000</td>
<td>2</td>
</tr>
</tbody>
</table>

Types: 1 = dune foot, 2 = beach, 3 = shoreface

Table 6.1 Applied nourishments at Egmond

6.7 Conclusions

The coastline around Egmond is stable on the long term scale. Measurements of shorelines indicate that the retreat of the coastline near Egmond has been stopped since 1843. However short scale variations in both time and space can be noticed on the seasonal scale. At certain moments the beach width does not satisfy to the demands regarding safety and recreation.

The shape of the intertidal beach at Egmond stays almost the same. At RSP 37.75 (Y = -250 m) the beach is extended in onshore direction while at RSP 38.50 (Y = 500 m) the beach is retreated. There seems to be a system which controls the general morphological development of the intertidal beach. The beach nourishment applied at the end of June 2000 between Y = 0 m and Y = 800 m, is not adopted by the system. Within a few months the intertidal beach changes to the shape it had before the intervention (extended near Y = -250 m and retreated near Y = 500 m).

Analysing the merged images shows that the outer bar crest elevation shows a depression between RSP 39.00 (Y = 1000 m) and RSP 38.00 (Y = 0 m). Furthermore the shoreface nourishment seems to have a slightly declined crest level southward of Y = 0 m. The beach southward of Y = 0 m is therefore less protected against the incoming waves, more sediment will be stirred up and transported in longshore direction. Northward of Y = 0 m the shallower shoreface nourishment and outer bar create a lee area and protect the beach from wave attack. In
the lee area the sediment can settle down as a result of the calmer wave conditions at that location. This may be the reason for the typical shape of the intertidal beach.

Longshore transport gradients in the inner nearshore zone are larger (about 2 times) during low wave conditions than during high wave conditions. The pattern of erosion and accretion along the shore during low wave conditions is very similar to the shape of the intertidal beach.

Historical data of beach volumes at Egmond show that beach nourishments have a relatively short lifetime. Often in a time span of 1 or 2 years the nourished sand has disappeared out of the intertidal beach.
7 Conclusions and recommendations

7.1 Conclusions

In this study an analysis is made of the development of the coastal area and the coastal processes at Egmond with application of Argus video images and the numerical model Delft3D.

Argus Video Monitoring techniques have been used to study the morphology at Egmond over the period of June 1999 to September 2001. Several processing and post-processing tools have been applied. Starting point of this study is formed by the hypothesis defined by Caljouw (2000) who also used Argus Video Monitoring techniques to evaluate the behaviour of the combined beach and shoreface nourishment at Egmond:

- The former outer bar governs the morphological development of the beach;
- Shoreface nourishment disturbs the equilibrium.

In continuation of the study performed by Caljouw and in line with the hypothesis mentioned above, two main objectives of this study are defined:

- To evaluate the effect of the shoreface nourishment on the morphodynamics at Egmond with the help of Argus Video Monitoring techniques and Delft3D.
- To evaluate to what extent the outer bar governs the development on the beach.

7.1.1 Analysis techniques

With the renewed version of the Intertidal Beach Mapping tool it is possible to map shorelines further away from the camera. With the possibility to adapt the region of interest manually, shorelines can also be mapped for less optimal image quality conditions. The mean deviation of the overall model varies between 0.1 m close to the camera and 0.3 m far away from the camera (in vertical sense). Standard deviations are approximately 0.2 m.

The Loess interpolation method performs better on interpolating the mapped shorelines to beach profiles than a simple linear interpolation method. Although no improvement is found in the mean deviations the Loess interpolation method shows more consistency than the linear interpolation method.

The Argus Merge Tool is a powerful tool to analyse the behaviour of bars in the nearshore zone. Studying merged images, taken at moments wave heights exceed 1.5 m, give a good impression about the movement of the bars.

A Delft3D model has been set up successfully to gain more insight in the coastal processes at Egmond. Flow velocities, wave dissipation, wave setup and tide averaged transport are computed for a bathymetry with shoreface nourishment and without shoreface nourishment.

7.1.2 Morphodynamics at Egmond

Intertidal beach profiles have been gathered over the period of June 1999 to September 2001 on a monthly basis. This set of profiles provides a good impression of the changing morphology at the intertidal beach. Beach width and volume changes have been derived from the intertidal beach profiles. Bar dynamics are studied with merged and stacked images. The following conclusions are made:
The intertidal beach maintains its typical shape (throughout the seasons).

Generally erosion can be found at all longshore locations during the stormy winter months while beach recovering is observed during the calm summer months. The shape of the intertidal beach remains virtually constant throughout the observed period. Around Y = -250 m the beach is extended in onshore direction while around Y = 500 m the beach is retreated.

The artificial intervention by means of the beach nourishment at the end of June 2000 is not 'adopted' by the system.

The sand was nourished between Y = 0 m and Y = 800 m and extended the intertidal beach at that location with approximately 60 m. However only a few months later most of the nourished sand has disappeared out of the intertidal beach. In the summer of 2001 the location and the shape of the intertidal beach is almost the same as it was before the intervention, one year ago.

Variation in beach width can be noticed both in time and in space.

However, except for the location of the beach where the nourishment was applied, the width of the dry beach is consistent over the observed period of 28 months. Some increase in beachwidth occurs during the calm summer months while some decrease can be noticed during the stormy winter months. These seasonal variations in dry beachwidth are in the order of 40 m.

Merged images indicate alongshore variation in outer bar crest elevation.

Merged images have been collected on a monthly basis to study bar dynamics. The merged images indicate a depression in the outer bar crest elevation between Y = 200 m and Y = 1000 m. Between Y = -500 m and Y = 0 m the elevation of the outer bar crest is clearly higher than at other (longshore) locations. Besides this the crest of the shoreface nourishment seems to be a bit lower southward of Y = 0 m than northward of Y = 0 m.

The shoreface nourishment disturbs the equilibrium of the three bar system.

After the accomplishment of the shoreface nourishment in summer 1999 the outer bar between Y = 1000 m and Y = -1000 m starts moving in onshore direction, fastest at Y = -150 m and over more than 100 m. In November 2000 the inner bar southward of Y = 0 m has broken lose from the inner bar northward of Y = 0 m and moved in onshore direction. The outer bar between Y = 200 m and Y = 1000 m has almost decayed then. In December the inner bar southward of Y = 0 m is attached to the outer bar southward of Y = 0 m. The outer bar southward of Y = 1000 m has attached to the shoreface nourishment.

Comparing tide-averaged transports show potential for large net circulations.

For high wave conditions (northwest and southwest) longshore transport rates in case of a simulation without shoreface nourishment and in case of a simulation with shoreface nourishment are approximately equal. The shoreface nourishment does not have much effect on the longshore transports in the inner nearshore zone. However, comparing tide-averaged transports for the different bathymetries indicate a potential for large net circulations probably initiated by wave setup differences. The influence of these large net circulations is not clear yet.

7.1.3 Interpretation of processes at Egmond

Merged images indicate gradients in the outer bar crest elevation. As a result, longshore gradients in wave dissipation will occur. Waves coming in from a certain direction will dissipate less on the outer bar where the crest is lower (between Y = 200 m to Y = 1000 m). Consequently more energy is left to enter the nearshore zone. The beach behind this part of the outer bar is therefore less protected against the incoming waves and more offshore directed (cross-shore) transport of
sediment will occur. On the contrary the part of the outer bar with a higher bar crest elevation (between \( Y = -500 \) m to \( Y = 0 \) m) creates a lee area and protect the beach from wave attack. Less offshore directed transport of sediment occurs. This (alongshore) variation of cross-shore transport may contribute to the typical shape of the intertidal beach.

With the results obtained from Delft3D, tide-averaged longshore transport gradients within the inner nearshore zone were computed. The inner nearshore zone is defined as the area between the inner bar and the intertidal beach. Although transport rates are small during low wave conditions, gradients in tide-averaged longshore transport are much (about 2 times) larger than during high wave conditions. Since low wave conditions mostly occur during the year, the pattern of erosion and accretion caused by the longshore transport gradients in case of low wave conditions, will play an important role in the morphological development of the intertidal beach.

When looking at the longshore transport gradients (in case of low wave conditions), erosion can be found between \( Y = 500 \) m and \( Y = 1000 \) m and around \( Y = -700 \) m. Accretion takes place between \( Y = -500 \) m and \( Y = 400 \) m. This pattern of erosion and accretion is very similar to the shape of the intertidal beach.

No direct effect of the shoreface nourishment on wave dissipation patterns in case of low wave conditions has been noticed. In case of high wave conditions, effect of the shoreface nourishment on wave dissipation can be seen at the outer bar but still not at the inner bar or swash bar. This is however according to the present computation, carried out with a bathymetry dated right after the completion of the shoreface nourishment. Still there may be an indirect effect as a result of the onshore movement of the outer bar after the completion of the shoreface nourishment. This indirect effect demands further research.

Based on the interpretation of the observations obtained with the Argus Video Monitoring techniques and the results of Delft3D the following hypotheses are defined:

- High waves dominate the morphological development of the intertidal beach – due to alongshore gradients in the outer bar crest elevation alongshore variation in cross-shore transport occurs, causing the typical shape of the intertidal beach.

- During low wave conditions longshore transport contribute to this pattern of erosion and accretion.

Two reasons can be given why after the completion of the shoreface nourishment the nourished sand disappears relatively fast out of the intertidal beach, especially between \( Y = 200 \) m and \( Y = 1000 \) m:

- The nourishments have not affected the depression in the outer bar crest elevation, which is primarily responsible for gradients in sediment transport.

- During low wave conditions the gradients in longshore transport are not taken away by the shoreface nourishment, they may even increase.
7.2 Recommendations

7.2.1 Argus Video Monitoring

Intertidal beach profiles and merged images have been collected on a monthly basis for over more than two years (28 months). Remarkable behaviour of the beach but especially of the bars was noticed throughout the observed period. Continuation of monitoring is necessary to better understand the morphodynamics at Egmond. Important questions are: will the appearance of the intertidal beach stick to its typical shape for another year and have the bars reached a new equilibrium?

Another recommendation concerns the development of an intertidal beach indicator which correlates with the MCL-zone. Coastal managers need simple objective indicators of the main beach system. Decision-making with regard to nourishing is based on MCL-volumes. Until now the MCL-volumes are determined out of bathymetric survey data. It is expected that MCL-volumes are correlated to the volumes of the intertidal beach. If so, maybe in the future expensive survey campaigns would be unnecessary?

7.2.2 Delft3D Egmond model

The Delft3D Egmond model has been set up to study the physical processes in the nearshore zone. Several wave conditions have been simulated with the model. The choice of the wave conditions was made by the expectation that high wave conditions would have more impact on the morphological development. However, studying alongshore transport rates showed that largest transport gradients in the inner nearshore zone occur during low wave conditions instead of high wave conditions. It is therefore recommended to do more simulations with various wave conditions to better understand the effect of the waves on the longshore transport.

The bathymetries used in the Delft3D model were based on the bathymetry of September 1999. At this time the shoreface nourishment was completed. As could be seen from the merged images the morphological system got very active and the outer bar started moving in onshore direction. After one year the bathymetry of the nearshore zone has changed completely. It would be useful to set up the Delft3D model with a more recent bathymetry.

Comparing tide-averaged transports of a bathymetry without shoreface nourishment and with shoreface nourishment show a potential for large net circulations. However further study is needed. Comparing wave-setup patterns for the different bathymetries may give more insight in these processes.
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A. Rectification process
1. Introduction

Before the information of an image can be used for coastal studies it is important to take into account some photogrammetric techniques. At first the coordinates of all pixels in the image have to be transformed to real world coordinates in order to find the real position of a certain feature observed in the image. The derivation of the equations used for rectification of an oblique image is presented after Lippmann and Holman (1989).

2. The rectification process

Rectification means the transformation from image coordinates to real world coordinates. Images are two-dimensional whereas the real world is three dimensional. This means the equations for the rectification process are only fully defined when transforming real world coordinates to image coordinates and not the other way around. In that case one ground coordinate has to be known. Since we are interested in processes occurring at the water surface, the problem is solved by assuming that the z-coordinate in the whole nearshore zone is equal to the sea level. The errors in the transformation, occurring from the moving watersurface (of the order of the wave amplitude) are assumed negligible compared to the height of the camera. For the Argus site ‘Jan van Speijk’ (camera height of 43 m) the errors in the transformation are smaller than 2 %.

The conventions as used in Argus image transformation are shown in Figure A.1. Here, image coordinates, located in the focal plane, are denoted with small letters (x,y), while for the coordinates in the ground plane capital letters (X,Y) are being used. The optic centre of the camera is located at point O, at a distance Zc above the ground plane. The other parameters are:

- N = Nadir : the vertical projection of O on the ground plane. It is the origin of the ground coordinate system
- Nadir line : line connecting O and N
- fc = focal length : distance between the focal plane and O
- p : centre of the focal plane (principal point)
- P : centre of the ground plane
- principal line : bisection line of the focal respectively ground plane
- optic axis : axis through O, p and P
- τ = camera tilt : angle between the optic axis and the nadir line
- q and Q : location of any point in the focal and ground plane respectively
Conventions in Argus photogrammetry (Lippmann and Holman, 1989)

The ground coordinates \((X,Y)\) can be derived directly from the image coordinates using the following relations:

\[
X_Q = \frac{Z_c}{\cos(\tau - \alpha)} \tan \gamma
\]

\[(1)\]

\[
Y_Q = Z_c \tan(\tau - \alpha)
\]

\[(2)\]

The angles \(\alpha\) and \(\gamma\), which determine the actual position in the ground plane with regard to the optic axis, are defined as:

\[
\alpha = \arctan \left( \frac{y_q}{f_c} \right)
\]

\[(3)\]

\[
\gamma = \arctan \left( \frac{x_q}{\sqrt{x_q^2 + y_q^2}} \right)
\]

\[(4)\]

However, when applying these expressions there are a few difficulties. One of the problems is the determination of the camera tilt \(\tau\) and the focal length \(f_c\), both are hard to measure or estimate.

For the focal length the problem is solved by counting pixels from the screen and relate them to the field of view of the camera. To do this the following expression can be used:

\[
f_c = \frac{x_e}{\tan \left( \frac{\delta}{2} \right)}
\]

\[(5)\]

where \(x_e\) represents the measured distance from the principal point \(p\) to the right-hand edge of the image and \(\delta\) the field of view of the camera. Nevertheless, this method introduces the field of view of the camera \(\delta\), which is also hard to measure in the field.

The other problem considers the definition of the coordinate system. All cameras are aimed in such a way, giving the best possible view of the nearshore. This results in a coordinate system which does not correspond with the more practical and generally used coordinate system, where the axes are shore-normal (X-axis) and -parallel (Y-axis). The necessary angle of rotation between the two coordinate systems \(\varphi\) and also the camera roll \(\theta\), which is the angle between the camera relative to the horizon, are both parameters which can also not be measured accurately in the field.
Thus, before an oblique image can be projected onto a horizontal plane with a certain z-level (rectification), four parameters have to be solved: $\delta$, $\tau$, $\varphi$ and $\theta$. Determination of these parameters in the rectification process requires so-called Ground Control Points or GCP's. The GCP's are fixed objects in the field of view of the camera from which the exact location is known.

By also knowing the image coordinates of a GCP, equation (1) and (2) give two relationships between image coordinates and ground coordinates. So, to solve all four unknown parameters at least two GCP’s are necessary. For optimalization of the solution often more than two GCP’s are being used. When done accurately, the errors are about $0.25^\circ$ for $\tau$, $0.5^\circ$ for $\varphi$ and $1\%$ for $f_c$ (Lippmann and Holman, 1989). These kind of errors are subpixel and therefore smaller than the error in pixel resolution.
B. Determination of horizontal location of the waterline from video
Determination of horizontal location of the waterline from video

(Source: Aarninkhof and Roelvink, 1999)

The method according to Aarninkhof and Roelvink is based on the color difference between pixels at the dry respectively wet beach. Generally, image intensities are defined in the RGB colour space, where the colour of each pixel is defined as a mixture of red, green and blue (RGB). In view of the present application, pixel intensities within a region of interest are converted to the HSV (Hue Saturation Value) colour space. The reason to do so is that the HSV colour space separately treats the colour information (by means of H and S) and the grayscale information (by means of V), see Figure B.1.

The value of H is defined along the surface of the cone and ranges between 0 and 1, running through the color spectrum from red (H = 0) via orange, yellow, green (H = 0.5), blue, purple and back to red (H = 1) again. The value of S, also ranging between 0 and 1, indicates the degree of saturation, which is 1 for the primary (red, green, blue) and secondary (cyan, magenta, yellow) colors and 0 for black and white. Grayscale information is incorporated via the value of V, in analogy to conventional black and white images.

Figure B.2a shows a histogram of raw Hue-Saturation values obtained from all pixels within the region of interest (ROI), after scaling these between zero and 1. Dry respectively wet pixels turn out to form well-separated clusters in HS space. Hence, the HS values of a single pixel indicate whether this pixel is dry or wet. This means that all pixels within the region of interest can be categorized, based on their HS values. Thus the key-issue is to define a discriminator function \( \psi \), which separates the clusters of dry and wet pixels. The determination of a discriminator function is obscured by the spiky appearance of the histogram of scaled intensities (Figure B.2a). Iterative low-pass filtering of the spiky data yields a smooth histogram with two well pronounced peaks \( P_{dry} \) and \( P_{wet} \), which mark the locations of the clusters of dry and wet pixels (Figure B.2b).
Based on the smoothened histogram of scaled image intensities, a discriminator function $\psi$ is determined according to

$$\psi(H, S) = p_1 \cdot H + p_2 - S$$

where $H$ and $S$ are the values of Hue and Saturation in every single pixel, scaled between 0 and 1. The function $\psi$ adopts positive values for dry pixels, while wet pixels yield negative values. A value zero is obtained at the interface of both areas, along a line $m: S = p_1 \cdot H + p_2$. The coefficients $p_1$ and $p_2$ are determined from the smoothened histogram, such $m$ crosses the saddle point of the histogram, while it is oriented perpendicular to the line between the two peaks (Figure B.3).

The discriminator function $\psi$ is being applied to all pixels within the region of interest, which yields positive values at the dry beach and negative values at the wet beach. The location of the waterline coincides with the locations where $\psi$ changes sign. The latter can be determined with the help of edge detection techniques. This yields a raw estimate of the position of the waterline in terms of screen coordinates of the oblique image. Using a set of sophisticated video imaging techniques...
(Holland et al, 1997), these screen coordinates are translated into real-world coordinates. The final estimate of the location of the waterline is obtained after averaging across the swash zone (taking into account local pixel resolution) and applying criteria regarding longshore consistency of the identified waterline. An example of a model result is shown in Figure B.4 (see below).

The middle right panel of Figure B.4 shows an oblique time exposure image of Egmond station ‘Jan van Speijk’, including the user-defined region of interest. Pixel intensities within this area of interest are categorized according to their Hue-Saturation, which yields the histogram shown in the upper right panel. For reliable results, the dry and wet peaks need to be well-separated and well-pronounced. This can be verified from the distance between the two peaks, in association with the spreading of intensity values within each peak (indicated by the crosses in the histogram, see Figure B.4). The present example obeys these criteria. Application of the discriminator function to the region of interest yields the middle left panel, where bright colors indicate positive values of $\psi$ and dark colors represent negative values. The waterline is determined at the interface of negative and positive values of $\psi$. This yields an estimate of the location of the waterline in terms of real-world coordinates, as shown in the lower panel. The vertical axis is pointing seaward, while the alongshore horizontal axis is directed toward the south. The camera is located near the origin of the axis system. As can be seen, beach width considerably decreases at larger distance from the video station.
The technique discussed above identifies a waterline with the help of a discriminator function, which is determined on an image by image base. This means that no site- or camera-dependent empirical relationships are involved, nor that the model needs to be trained for a suit of images obtained from a specific camera. Consequently, the model allows for flexible application to different Argus sites. Successful model application to Argus images from Palm Beach (Australia), Noordwijk (The Netherlands) and Egmond (The Netherlands) has proven the generic applicability of the color-based approach.

Figure B.4 Identification of waterline from Argus color images, example Jan van Speyk, camera c1
C. Determination of the vertical beach elevation from the hydrodynamics


Determination of the vertical beach elevation from the hydrodynamics

This section introduces a model to estimate the vertical elevation of shorelines, observed from video. The combination of a shoreline detection model and a shoreline elevation model enables the mapping of intertidal beach bathymetry. The elevation model should account for the processes which govern the location of the shoreline as identified from ten-minute time averaged video images. At this time scale, these processes are wind, tide, wave set-up and swash. Figure C.1 illustrates the contribution of each process, by showing an artificially generated time stack of swash run-up on a plane beach with slope \( m \). The energy spectrum of the swash is dominated by short waves with a period \( T_{peak} \) and long waves with a period \( 7T_{peak} \). \( Z_{SWL} \) represents the still water level immediately outside the surf zone and accounts for the current tidal elevation and the wind-induced set-up of the mean water level. Dissipation of wave energy induces an additional set-up \( \eta \) of the mean water level in the surf zone.

![Figure C.1 The effect of tide, wave set-up and swash on the time-averaged location of the waterline as observed from video](image)

To set up the shoreline elevation model, it is important to assess at what location near zero water depth the video based detection model identifies the shoreline. Three different scenarios are treated here.

In absence of sea and swell, no swash oscillations occur, hence the location \( x_{sl} \) of the shoreline is found at \( x_{SWL} \) (Figure C.1). The associated shoreline elevation \( z_{sl} \) is governed by tide and wind only, which yields the simplest elevation model:

\[
  z_{sl} = z_{SWL}
\]  

In the presence of sea and swell, wave breaking induces a set-up \( \eta_{sw} \) of the mean water level at the shoreline, as well as an oscillation of the instantaneous location of the waterline. The effect of swash can be ignored if the location of the video based shoreline accurately matches the ten-minute time averaged location \( x_{avg} \) of the waterline (Figure C.1). This yields the second scenario, which accounts for tide, wind and wave set-up to determine \( z_{sl} \):

\[
  z_{sl} = z_{avg} = z_{SWL} + \eta_{sw}
\]  

Depending on the background of a shoreline detection model, it may as well identify a shoreline location \( x_{osc} \) associated with a certain percentage of swash exceedence rather than the time-averaged waterline location \( x_{avg} \). Scenario 3 accommodates these models by accounting for the
oscillating swash component. The combination of long and short waves induces a swash zone with width $\Delta x_{osc}$ (represented by the gray-shaded area in Figure C.1). Assuming a plane beach with slope $m$, a width $\Delta x_{osc}$ corresponds to a vertical swash height $\Delta z_{osc} = m \Delta x_{osc}$, centered around the time-averaged waterline elevation $z_{avg}$. Thus, the shoreline elevation according to Scenario 3 reads

$$z_{id} = z_{osc} = z_{SWL} + \eta_{sl} + \frac{K_{osc} \Delta z_{osc}}{2}$$

(3)

where $K_{osc}$ is an empirical coefficient ($-1 < K_{osc} < 1$) which accounts for different levels of swash exceedence. $K_{osc}$ depends on the type of shoreline detection model and is determined from model calibration against field data.

To allow for a generic application of the shoreline elevation model, Eq. (3) is taken as the starting point for model development. Consequently, $z_{SWL}$, $\eta_{sl}$ and $\Delta z_{osc}$ need to be quantified. This is done here by adopting the Janssen (1997) approach. Janssen (1997) determines $z_{SWL}$ from field measurements, preferably in shallow water depth. If unavailable, an astronomically predicted tidal level is taken as a proxy. The wave set-up $\eta_{sl}$ is computed from a wave decay model (e.g. Battjes and Janssen, 1978). As the beach profile is not necessarily known a priori, an equilibrium profile is used to estimate $\eta_{sl}$. Obviously, application of a theoretical equilibrium profile rather than the real world bottom profile introduces an additional error in terms of wave set-up at the shoreline. However, sensitivity runs by Janssen (1997) have shown that this error is only very marginal. Finally, the contribution $\Delta z_{osc}$ of the oscillating components is modelled by combining empirical expressions for the vertical excursion of surf beat and swash according to Eq. (4):

$$\Delta z_{osc} = 0.02 \sqrt{ \frac{2 H_{sig} L_o}{1 + \left(2 \xi_b - 0.4 \xi_b^2 \right) H_b}$$

(4)

The first term on the right hand side of Eq. (4) represents the vertical excursion of surfbeat at the shoreline (after Goda, 1975), which depends on the deep water significant wave height $H_{sig}$ and the deep water wave length $L_o$. The last term includes the vertical excursion of swash. This expression was obtained by combining the effect of run-up (after Hunt, 1959) and run-down (after Battjes, 1974), which are both expressed in terms of the Irribarren number $\xi_e$ at the inner most breaker bar and the breaker height $H_b$ at that location. The empirical coefficient $K_{osc}$ (Eq. 3) is set to 0.9 for application of the shoreline detection model to video data from Egmond. The latter value was obtained from the model ground truthing against a set of GPS-surveyed waterlines.
## D. Contour plots

### June 1999 - September 2001

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Evaluation of Nourishments at Egmond Z28 22.5 1  July, 2002

Cross−shore (m) | Longshore (m)
---|---
−0.3 | −0.3
−0.3 | −0.3
−0.3 | −0.3
−0.3 | −0.3
−0.3 | −0.3
−0.1 | −0.1
−0.1 | −0.1
−0.1 | −0.1
−0.1 | −0.1
0.1 | 0.1
0.1 | 0.1
0.1 | 0.1
0.1 | 0.1
0.3 | 0.3
0.3 | 0.3
0.3 | 0.3
0.3 | 0.3
0.5 | 0.5
0.5 | 0.5
0.5 | 0.5
0.5 | 0.5
0.7 | 0.7
0.7 | 0.7
0.7 | 0.7
0.7 | 0.7
0.9 | 0.9
0.9 | 0.9
0.9 | 0.9
0.9 | 0.9

July 2000

August 2000

September 2000

October 2000
Evaluation of Nourishments at Egmond

July, 2002

Cross-shore (m)
Longshore (m)

-0.3
-0.3
-0.3
-0.3
-0.3
-0.3
-0.1
-0.1
-0.1
-0.1
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0.9
0.9
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0.9

November 2000
December 2000
January 2001
February 2001

Cross-shore (m)
Longshore (m)
# E. Intertidal Beach Profiles

**July 2000 - September 2001**

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Evaluation of Nourishments at Egmond

Intertidal Beach Profile - October 2000

Intertidal Beach Profile - November 2000

Intertidal Beach Profile - December 2000
Evaluation of Nourishments at Egmond

Intertidal Beach Profile - April 2001

Intertidal Beach Profile - May 2001

Intertidal Beach Profile - June 2001
F. Analysis of the Intertidal Beach
June 1999 - September 2001
Evaluation of Nourishments at Egmond

Mean beachwidth at MLW and MHW (incl. max and min width) – section 3

Monthly accretion / erosion and cumulative changes – section 3

Wave height Hrms

Stacked image along array y = 400 m
Evaluation of Nourishments at Egmond

Mean beachwidth at MLW and MHW (incl. max and min width) – section 8

Monthly accretion / erosion and cumulative changes – section 8

Wave height Hrms

Stacked image along array y = -600m
### G. Erosion/sedimentation plots

**July 2000 - September 2001**

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Evaluation of Nourishments at Egmond Z282 22.5 1 July, 2002

WL | delft hydraulics

Accretion / erosion (m)

August 2000

September 2000

October 2000

November 2000
Evaluation of Nourishments at Egmond

April 2001

May 2001

June 2001

July 2001
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J. Tidal averaged longshore transport
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Without shoreface nourishment.

Figure J.2 Longshore transport - Northwest and Southwest high wave condition. 
Symmetric shoreface nourishment
Figure J.3 Longshore transport - Northwest and Southwest low wave condition.

Symmetric shoreface nourishment

Figure J.4 Longshore transport - Northwest and Southwest high wave condition.

Asymmetric shoreface nourishment
K. MCL volumes - between dune foot and MLW
L. Delft3D - figures
Egmond model
Bathymetry
Egmond model: without shoreface nourishment
Flow velocity, Northwest high
HW, LW, Max. Ebb, Max. Flood
Egmond model: without shoreface nourishment
Flow velocity, Southwest high
HW, LW, Max. Ebb, Max. Flood

WL | DELFT HYDRAULICS
Z2822 | Fig. A.2
Egmond model: without shoreface nourishment
Wave setup, Northwest high
HW, LW, Max. Ebb, Max. Flood
Egmond model: symmetric shoreface nourishment
Flow velocity, Northwest high
HW, LW, Max. Ebb, Max. Flood
Egmond model: symmetric shoreface nourishment
Dissipation, Northwest high, Southwest high
HW, LW
Egmond model: symmetric shoreface nourishment
Wave setup, Northwest high
HW, LW, Max. Ebb, Max. Flood
Egmond model: symmetric shoreface nourishment
Wave setup, Southwest high
HW, LW, Max. Ebb, Max. Flood
Egmond model: symmetric shoreface nourishment
Tide-averaged total transport, Northwest high, Southwest high

WL | DELFT HYDRAULICS

Fig. B.6
Egmond model: symmetric shoreface nourishment
Flow velocity, Southwest low
HW, LW, Max. Ebb, Max Flood

WL | DELFT HYDRAULICS

Z2822  Fig. B.8
Egmond model: symmetric shoreface nourishment
Wave setup, Southwest low
HW, LW, Max. Ebb, Max. Flood

WL | DELFT HYDRAULICS
Egmond model: symmetric shoreface nourishment
Tide-averaged total transport, Northwest low, Southwest low

Fig. B.12
Egmond model: asymmetric shoreface nourishment
Flow velocity, Northwest high
HW, LW, Max. Ebb, Max. Flood
Egmond model: asymmetric shoreface nourishment
Flow velocity, Southwest high
HW, LW, Max. Ebb, Max Flood

WL | DELFT HYDRAULICS
Z2822  Fig. C.2
Egmond model: asymmetric shoreface nourishment
Dissipation, Northwest high, Southwest high
HW, LW

WL | DELFT HYDRAULICS

Fig. C.3
Egmond model: asymmetric shoreface nourishment
Wave setup, Southwest high
HW, LW, Max. Ebb, Max. Flood
Egmond model: asymmetric shoreface nourishment
Tide-averaged total transport, Northwest high, Southwest high
Egmond model
Tide-averaged total transport, Southwest high
Residual total transport - symmetric versus without

WL | DELFT HYDRAULICS

Z2822  Fig. D.2
Egmond model
Tide-averaged total transport, Northwest high
Residual total transport – asymmetric versus symmetric

WL | DELFT HYDRAULICS

Z2822

Fig. D.3