Coastline modelling with UNIBEST: Areas close to structures

MSc Graduation Thesis:
Impact of coastal structures in coastline models

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In cooperation with Deltaires and Boskalis

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Preface

This master thesis is written to finalize my master program 'Hydraulic Engineering', specialization 'Coastal Engineering', at the faculty of Civil Engineering at the Delft University of Technology. The work is done at the offices of Deltas (Delft) and Boskalis (Papendrecht).

This study concerns the hydrodynamic processes near coastal structures and the implementation of these processes into the coast line modeling software UNIBEST-CL+. Simple coastline models should also be able to calculate the effects of coastal structures to some extent. This study was initiated by ir. B.J.A. Huisman at Deltas.

Therefore, I would specially like to thank him first, as he was also my daily supervisor at Deltas. Besides him, also ir. K.G. Nipius was giving regularly advice on the research as being the supervisor from Boskalis. I would like to thank my committee members of the TU Delft; Professor M.J.F. Stive for being my graduation committee chairman and ir. A.P. Luijendijk and ir. M. Zijlema for their remarks, information and support during the research. Furthermore I would also like to thank the students (especially my roommates) and colleagues at both Deltas and Boskalis for their input and support.

Finally, and not the least important, I would thank my family and friends for supporting me, during this sometimes difficult time, in finishing this master study.

Guido van der Salm,
Delft, February 2013
Summary

This document aims at providing insight in approaches that can be used to model coastline development near structures in single line coastline models. The focus of this study will lay on the use of UNIBEST-CL, a single line coastline modelling package, developed by Deltares. Creating a coastline model in UNIBEST is rather user friendly, but if structures are present some extra work needs to be done to get reasonable output from the model. The standard approach of modelling structures in UNIBEST needs extra calculations of local wave climates in the shadow zone of structures. This can be done by hand, using formulations of Kamphuis and it can also be done by using a second modelling package called SWAN. Both these methods result in a more labour intensive calculation. Therefore, a third approach is developed, an automated module integrated in the package of UNIBEST-CL. This approach uses the same Kamphuis formulations mentioned earlier. The main difference is that it calculates the local wave climates at every cross-shore ray of the UNIBEST model. Within an average model this will generate more local wave climates compared to the manual approach, resulting in more input information. To compare these three different approaches two kinds of models are created. First a theoretical study is carried out. Secondly, the results of the theoretical study are used to be verified in a field case situation.

The theoretical study is based on two questions:

- How does the Automated Kamphuis approach perform compared to Manual Kamphuis calculations and SWAN calculations?
- Which modeling approach is suitable for what kind of conditions?

To investigate these questions, a simple, straight coastline is created with three shore normal groynes. The groynes have a length of 250 meters and the spacing between them is also 250 meters. This configuration is tested with several changeable parameters. The bottom profiles used are variations of a Dean profile, with steep nesses of 1:50, 1:100 and 1:200. Furthermore, there are four ‘types’ of wave climates used. A single direction from the Northwest, multiple directions from the Northwest, a symmetrical climate with multiple directions and a realistic climate, based on a North Sea climate. The first three climates are used with two types of wave conditions. First with a wave height of 2 meters and a period of 12 seconds and second with a wave height of 1.2 meters and a period of 8 seconds. This resulted in a total of 21 calculations.

All 21 calculations are carried out by the three approaches. The Automated Kamphuis approach only calculates the local climate points at the shoreline. The Manual Kamphuis approach is used to calculate the local climates at the shoreline, half way the groyne field and at the edge of the transport zone. The SWAN approach cannot be for locations at the shoreline, so only half way the groyne and at the edge of the transport zone are used. These different locations are chosen this way to determine the best suitable approach in different situations. Finally, this resulted in 21 runs, each containing 6 calculations from the different approaches.

After the calculations, the results are assessed by using a classification of the width of the transport zone divided by the length of the groynes. Using this classification, the results of all the runs are compared by looking at the resulting transport magnitude and the coastline shape. This leads to a final table that can be used as a recommendation on which approach to use in what kind of situation.
The results of the theoretical study are then used in a second calculation, to hindcast the coastline changes in a field application case at the beaches of Sitges, Spain. The coastline of Sitges contains a lot of coastal structures, but the northern stretch of the coastline is rather straight and contains 6 shore normal groynes. Therefore the situation is ideal to test the results of the theoretical study. The input of the model is kept rather simple, also because of the lack of detailed information. The bottom profile used, is just one cross shore profile taken at Sitges. The used wave climate is generated by a schematisation of a year of time series in front of the coast of Barcelona. During the field case testing not all variants of the three approaches are used. Only one SWAN approach and the Automated Kamphuis are compared. While running this coastline model multiple adjustment of the Automated module were needed. Some programming code in the software needed to be adjusted during the calculations. Finally, the field case resulted in satisfactory results for both approaches. The resulting coastlines from both SWAN and the Automated approach are similar in magnitude and shape. Comparing these results to a areal image shows that the modeled coastlines are not equal to the photograph. The average coast angle is quite representable, but the curvature at the groynes is underestimated by the models.

Some conclusions that can be drawn from both the theoretical and the field case study are summed here:

- The automated approach functions well compared to the manual approach with local climates at the shoreline. The results are even better because more local wave climates are generated, so more input information is given to the model.
- Using a classification ratio of width of transport zone divided by the length of the groyne one of the approaches can be chosen that will give the most optimal result in the specific situation.
- If the ratio is very small (e.g. a small width of transport compared to the groyne length) the best approach will be the SWAN approach, because the most processes are taken into account in this situation.
- With a larger ratio, Kamphuis, and therefore the Automated approach, will give better results, because it takes the effect of the structure into account, better than the SWAN approach.
- The result of the field case shows that the Automated approach also works well in real situations, compared to the outcome of the SWAN approach. The final result of the model does not match the situation in reality, but that difference must be found in different model components.

This study also has its imperfections and its incompleteness in certain aspects. Therefore, some recommendations are given to support future investigation on this subject.

- Future model creation can be based on the table scoring the different approaches, looking at the ratio between the width of the transport zone and the groyne length.
- This study has been performed for a mild wave climate with minimal tidal influence. To be able to use the different approaches in a wider variety of conditions the effect of tide can be investigated.
- The field case model should be performed on a situation of which there is more detailed information available. The information of physical parameters at Sitges was limited, resulting in a not accurate coastline change.
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1 Introduction

1.1 Background

All over the world, nice coastal areas can be found. People often build properties at attractive sites along beaches, like houses, boulevards and hotels. However, the question is if that same beach will still be there in several years, with the same nice view and the same nice surroundings. Or will that beach completely be eroded away, leaving nothing to enjoy behind? Coastlines that are subject to erosion can be protected in several ways. In general, a distinction is made between soft and hard measures. Soft measures are for instance nourishments. One can think of groynes, breakwaters and seawalls as examples as hard measures. But one has to know what measures can be used in what situations and how it will perform. Model predictions can be used to assess the performance of the measures taken. Several morphological models are available to predict coastline development. These models are used for coastal systems that are dominated by alongshore sediment transport. This transport determines the beach erosion and sedimentation rate. The alongshore transport is generated by wave driven longshore sediment transport processes. The partial variability in the conditions result in alongshore transport gradients. Erosion will occur when there is a positive gradient, and with a negative gradient there will be accretion. The cross-shore profile in these models is considered to remain the same. The advantage of these models is that they are fast and stable, and easy to use for a quick view into coastline changes.

The models described above are very suitable for modelling a uniform coastline. It becomes more time consuming when structures are introduced along a (straight) coastline. Because a structure has a lee side, or shadow zone, more detailed conditions are needed to make good model predictions in such an area behind the structure. It is possible to do this, but extra, separate runs are needed. This will be more time consuming.

At Deltares, Delft, the program UNIBEST-CL+ has been developed. This is a single line coastal modelling program like described above (See Appendix A for more detail on single line modelling). The standard approach to model structures in UNIBEST-CL+ requires extra computations of local conditions in the shadow zone of the structures. These extra computations need to be done by hand or with the use of a second modelling software package (SWAN) and therefore take extra time.

Recently however, a module is included in the UNIBEST-CL+ modelling software that automatically computes shielded wave climates in the shadow zones of structures. With this module, the modelling of the sediment transport near structures should take significantly less effort. But, as for all models, also in this approach the output depends on the input given to the model. It is expected that the applicability of the chosen approach for modelling the local climates in the sheltered area depends on several environmental parameters and different model settings. For example, the steepness of the foreshore, the width of the active zone, the wave impact angle and several more can have significant impact on the results of the approaches. This study will investigate the applicability of the different approaches for schematising local wave climates under different conditions and with different model settings.
1.2 Problem definition
Using behaviour based models, like UNIBEST-CL+, puts limitations on the applicability of the model. This kind of model does not take into account every morphodynamic process, taking place on the foreshore. It is valid for not very complex, unobstructed coastlines. But when a structure blocks the longshore transport the model is not capable of calculating what happens in the shadow zone of the structure by itself. Therefore, local wave climates have to be added on several places on the lee side of the structure. This works quite well, but can be rather labour intensive and time consuming. To reduce the labour intensity of this process, an addition is made to the UNIBEST-CL+ model which should be able to calculate these shadow zone processes and generate the local climates automatically. It should, however, be verified whether or not the model will perform as expected. Besides, it is not clear if the limitations to this module are influencing its results significantly for specific situations.

1.3 Goals
The goal of this study is to investigate three typical modelling approaches for the assessment of coastline changes near structures with coastline models. The performance of each approach to hindcast coastline development near structures needs to be quantified and compared. First a simplified situation will be studied. Secondly, the results of this study are tested in a field case situation. Additionally to these goals, a good understanding of the relevant processes near the coastal structures is important to be able to interpret the results of the testing correctly. The final goal of these studies would be to present guidelines for the applicability of the three different modelling approaches in coastline models near coastal structures (in this case UNIBEST-CL+).

1.4 Study approach
This study consists of multiple parts:

- At first, an investigation into the processes that take place close to coastal structures is done (Chapter 2). For this purpose a non-extensive model (Delft-3D) is used and some illustrations. In this study, several processes will be investigated like (1) water level set-up gradients (resulting in set-up driven currents / rip currents), (2) diffraction and sheltering behind structures, (3) refraction of waves on a sloping beach profile.
- Secondly, a number of model approaches are applied to model coastline development near a groyne (Chapter 3). This will be done for a simplified situation with a straight coast. Varying the placing of the local climates in the cross-shore direction in three approaches will give an insight in the applicability of these approaches.
- Thirdly, the most capable modelling approach that came forward from the simplified tests is applied on a field case for the coast of Sitges (Chapter 4). The final product of this study will be an advice on when to use the three different approaches in in coastline models.
2 Morphological processes near coastal structures

2.1 Introduction
This chapter provides insight in the different morphological processes that are of relevance for coastal morphological changes near to groynes. Section 2.2 describes a number of relevant processes, like refraction, diffraction and wave breaking. These are taken into account during the studies with UNIBEST-CL+ model in the following chapters. Furthermore, some model runs with a simplified Delft3D model are described, which provide information on the magnitude of different processes for varying situations.

2.2 Relevant processes near structures
This section provides an overview of processes that are of relevance for morphological evolution near to structures. The main focus is on the hydrodynamic forcing conditions for the morphological changes. Figure 2-1 shows a number of these processes, which are further elaborated on in the coming sections, like refraction, diffraction, sheltering, set-up driven currents and wave breaking.

2.2.1 Refraction
Refraction is one of the wave transformation processes that take place in the near shore area. During refraction the wave crests tend to bend to align themselves with the bottom contours. Figure 2-2 shows the basics of refraction along a straight coastline.

As can be seen, the deep water wave approaches from an angle towards the coast. The end of the wave crest closest to the coastline, experiences more influence from the water depth.
Because the wave celerity is depending on the water depth, according to equation 2.1, the shoreward end of the wave crest has a lower speed than the crest end in deeper water. This means the furthest end approaches the shore faster, due to which the crest turns towards the shore.

\[
C = \frac{L}{T} = \frac{gT}{2\pi} \tanh(kd) = C_0 \cdot \tanh(kd)
\] (1.1)

With:
- \(C\) Wave celerity \([\text{m/s}]\)
- \(L\) Wave length \([\text{m}]\)
- \(T\) Wave period \([\text{s}]\)
- \(g\) Gravitational acceleration \([\text{m/s}^2]\)
- \(k\) Wave number \(\left(\frac{2\pi}{\lambda}\right)\) \([\text{m}^{-1}]\)
- \(\lambda\) Wave length \([\text{m}]\)
- \(C_0\) Deep water wave celerity \([\text{m/s}]\)

For practical reasons, in a lot of calculations the depth contours are assumed to be parallel. Therefore the wave direction can be calculated with:

\[
\frac{\partial}{\partial x} (k \sin(\alpha)) = 0
\] (1.2)

With:
- \(\alpha\) Incoming wave angle \([\text{deg}]\)

After differentiation this results and the fact that the wave period remains the same we obtain:

\[
\frac{C}{\sin(\alpha)} = \text{const}
\] (1.3)

This is Snell's law and with this the angle of the refracted waves in the coastal zone can be calculated according to two locations on the cross-shore profile, which are indicated by the subscript indices.

\[
\frac{\sin(\alpha_2)}{\sin(\alpha_1)} = \frac{C_2}{C_1}
\] (1.4)

Because the assumption is made there is no energy loss across the wave rays (this would be diffraction, chapter 2.2.2), with the help of equation 2.5, the relationship between two wave heights can be found. The relationship is shown in equation 2.6.

\[
\text{const} = n \cdot C \cdot E \cdot b
\] (1.5)

\[
\frac{H_2}{H_1} = \sqrt{\frac{n_1 C_1 b_1}{n_2 C_2 b_2}}
\] (1.6)

With:
- \(n_i\) Energy flux parameter \(C_0 / C = \sqrt{1 + \frac{b_i}{b_{\text{in}}}}\) \([-]\)
- \(b_i\) Distance between the adjacent wave rays at location \(i\) \([\text{m}]\)
- \(E\) Wave energy density \(\left(\frac{k}{\rho g H^2}\right)\) \([\text{J/m}^2]\)
- \(H_i\) Wave height \([\text{m}]\)
This can be related to deep water to get the *Refraction coefficient (eq. 2.7)*:

\[
K_r = \sqrt{\frac{b_0}{b}}
\]

(1.7)

With:

- \(K_r\): Refraction coefficient [−]

This coefficient can also be related to Snell’s Law:

\[
K_r = \sqrt{\frac{\cos(a_0)}{\cos(a)}}
\]

(1.8)

### 2.2.2 Diffraction and sheltering

Wave diffraction takes place if wave energy is transported perpendicular to the wave propagation direction. Where with refraction no energy transport takes place across the wave rays (Figure 2-2 above), diffraction is concerned with transport of energy across the wave ray. It is noted that in reality wave refraction and wave diffraction cannot be separated. Diffraction, typically, takes place if there are sudden obstructions of the waves, like groynes, shore parallel breakwaters (Figure 2-3), sudden shallow banks, small islands, etc.

![Figure 2-3: Basic diffraction](image)

Figure 2-3 shows a breakwater parallel to the incoming wave crests. When the wave crest reaches the breakwater it will be blocked and possibly partially be reflected, while the waves will not be obstructed beyond the tip of the breakwater. Behind the breakwater there is a shadow zone with no wave action. The large gradient in wave energy in alongshore direction will trigger an exchange of energy across the fictive line from the tip of the structure towards the shore. Crests of the groyne will spill into the sheltered area, troughs will be filled with water from the quiet area. Therefore the wave rays will turn from the tip of the construction into the sheltered area.

Like refraction, also the impact of diffraction on the wave energy can be indicated with a coefficient, \(K_d\). But \(K_d\) is not as easily defined as \(K_r\). Multiple studies have been performed and several diffraction templates have been found for different situations. Goda (1985) for example performed a study on irregular, directional waves. He did find a \(K_d\) of about 0.7 along the shadow line.
CERC (1984) looked into diffraction coefficients of incident waves at an angle to a structure. Kamphuis (1990) extended the findings of Goda, and created some schematised expressions for refraction / diffraction behind a structure. This will be elaborated further in chapter 3.4. Figure 2-4 shows the diffraction graph along a single breakwater according to CERC (1984).

![Diffraction Graph](image)

**Figure 2-4: Diffraction coefficient according to CERC (1984)**

It clearly shows the diffraction coefficients along the different wave rays, both in the shadow and the undisrupted area. Along the line separating the shadow area from the wave zone the diffraction coefficient was found to be 0.6-0.7. This value is considered reasonable for irregular wave climate conditions with realistic, 2 dimensional wave spectra. Further into the wave area it will reach 1.0 again (undisturbed waves).

**Sheltering**

Sheltering is not quite the same as diffraction. It also is about the blocking of waves by a structure but with diffraction wave energy is transported across the wave rays. With sheltering wave conditions are just taken out of the equation when they are blocked by the structure. This means wave energy is lost. Besides the loss of energy, also the mean direction of the total wave climate changes. In practice, however, it is found that wave sheltering accounts for the most dominant effects of structures on waves for situations with some directional spreading of the waves.

![Sheltering Diagram](image)

**Figure 2-5: The principle of Sheltering**
2.2.3 Wave breaking

As waves approach the shore, due to the process called shoaling the wave height could theoretically increase to infinity.

\[ \frac{H_2}{H_1} = \sqrt{\frac{c_1}{c_2}} \frac{n_1}{n_2} \]  

(1.9)

In reality wave height is limited. The maximum wave height is depending on the steepness of the wave. When the particle velocity in the crest exceeds the overall crest velocity, the wave starts breaking. On average the maximum wave angle is about 120 degrees.

Miche (1944) expressed the wave steepness limiting with the help of Stokes wave theory:

\[ \frac{H_b}{L_b} = 0.142 \tanh(kh) \]  

(1.10)

With:

- \( h \) water depth [m]

If equation (1.10) is exceeded by the deep water wave steepness white capping occurs. White capping is a steepness limited kind of wave breaking.

In shallow water equation (1.10) transforms to:

\[ \frac{H_b}{L_b} = 0.142(kh) = 0.142 \left( \frac{2\pi h}{L} \right) = 0.88 \frac{H}{L} \]  

(1.11)

\[ \gamma = \frac{H_b}{h_b} = 0.88 \]  

(1.12)

With:

- \( \gamma \) Breaker index [-]
- \( H_b \) Wave height at the breaker line [m]
- \( h_b \) Water depth at the breaker line [m]

Equation (1.12) is also called depth induced breaking. Due to shoaling the wave celerity decreases, but the horizontal particle movement increases due to decreasing depth and increasing wave height. Because of the reduction of the water depth the orbital wave movement becomes more elliptical and the horizontal particle movement increases. When the velocity of this movement exceeds the wave crest celerity, wave breaking occurs.

2.2.4 Set up driven currents

Energy dissipation due to wave breaking assumes that the water depth is proportional to the water depth by the breaker index ‘\( \gamma \)’ (see equation 2.12).

Due to this and the shallow water approximations, the radiation stress \( S_{xx} \) decreases in the surf zone, in onshore direction and the resulting negative gradient \( \frac{\partial S_{xx}}{\partial x} < 0 \) creates an onshore directed force \( F_x \). This force needs to be balanced, and this is done by an increasing
pressure force in offshore direction. The increasing pressure force is generated by the raising of the water level, the Set-Up. The maximum set-up that can be generated is equal to:

\[ h_{ws} = \frac{5}{16} \gamma H_b \]  

(1.13)

With:
- \( h_{ws} \): Waterlevel set-up [m]

In case the shoreline is disturbed by some kind of structure, there will be a sheltered area. Due to diffraction, described in the previous chapter, the wave height behind the structure will be decreased. Therefore also the wave induced set up will be less compared to the undisturbed area. Due to this, a difference in water level is generated and this gradient drives a current towards the structure. When the current reaches the structure it is forced out towards the sea again. This creates an eddy that is driven by the set up difference.

![Figure 2-6: Set-up driven current towards the groyne structure](image)

2.2.5 Wave driven longshore current

The model that we use in this investigation is a single line model (Appendix A). This kind of modelling is based only on longshore sediment transport. No sediment is lost in the cross-shore direction. The driving force behind the longshore transport is the longshore current.

If waves are approaching the shore under an angle, there is a force from the waves on the water. This force is generated by the horizontal gradient of the radiation stress, which by itself is described by the excess momentum flux due to the presence of waves. Radiation stresses consists of two components. First there is the pressure part due to the wave induced pressure, \( \rho \text{wave} \), and second there is a transfer of momentum, \( \rho \ddot{u} \), trough the vertical plane. The stresses can be divided into two kinds of stresses: Normal stresses (\( S_{xx} \) and \( S_{yy} \)) and Shear stresses (\( S_{xy} \)).

\[
S_{xx} = (n - \frac{1}{2})E + n \cos^2 \theta \dot{E} = \int_{-h}^{0} (\rho u_x) u_x dz + \int_{-h}^{0} \rho \text{wave} dz 
\]

(1.14)

\[
S_{yy} = (n - \frac{1}{2})E + n \sin^2 \theta \dot{E} = \int_{-h}^{0} (\rho u_y) u_y dz + \int_{-h}^{0} \rho \text{wave} dz 
\]

(1.15)

\[
S_{xy} = n \sin \theta \cos \theta \dot{E} = \int_{-h}^{0} (\rho u_x u_y) dz 
\]

(1.16)

With:
- \( n \): Ratio of group velocity and phase celerity [-]
- \( u_x \): Particle velocity in X-direction [m/s]
- \( u_y \): Particle velocity in Y-direction [m/s]
- \( \rho \): Mass density [kg/m³]
The longshore current is driven by one of the components described above. Actually it is
driven by the cross-shore rate of variation of the shear component of the radiation stress $S_{yx}$.
The counter acting force of this driving force ($F_y$) is created by the bed shear stress ($\tau_{b,y}$)
that develops when a currents is created. This results in:

$$F_y = -\frac{dS_{yx}}{dx} = \tau_{b,y}$$

(1.17)

According to the quadratic friction law the equation for the bed shear stress becomes;

$$\tau_{b,y} = \frac{1}{\pi} \rho c_r \sqrt{gh} \frac{H}{h} V$$

(1.18)

With:
- $\tau_{b,y}$ Bed shear stress [N/m²]
- $c_r$ friction coefficient [-]
- $V$ Longshore current velocity [m/s]

Combining (1.17) and (1.18) will lead to the longshore current velocity $V(x)$ for a uniform
costline:

$$V(x) = -\frac{5}{16} \pi c_r g \sin\phi_0 h \frac{dh}{dx}$$

(1.19)

With:
- $H/h$ [Assuming a constant ratio of $H$ over $h$, and no lateral dispersion]
- $\phi_0$ incoming wave angle [deg]
- $c_0$ deep water phase celerity [m/s]
3 Evaluation of modelling approaches near structures

3.1 Introduction
This chapter describes the performance of three modelling approaches for coastline modelling in sheltered areas. Various types of coastal situations are modelled with these approaches and the results are compared. In the next chapter the conclusions from this theoretical study will be used and tested in a field case to see if the approaches work satisfactory in practical use.

The chapter starts with describing the different approaches that can be used to obtain local wave climates in the sheltered area behind a groyne structure (Section 3.4). The next section describes the different local climate positions and further model input of the UNIBEST and Delft3D models. Also, the different scenarios, used in both models, are provided. The analyses of the results and interpretation of the findings is given in section 3.6. After that, sensitivity analyses are made on specific parameters used in both models. Finally the conclusions on the applied modelling approaches, in the theoretical study, are summarised.

3.2 General Model Setup
The UNIBEST-CL+ models consist of two parts, the UNIBEST-LT and UNIBEST–CL modules. The first calculates the cross-shore sediment transport distribution according to a certain profile, a given wave climate and some additional parameters. The –CL module uses the transport calculations of the –LT module and the input of a coastline to calculate the coastline changes on that coast. This section will elaborate on the different input and model parameters of these two modules.

Groyne placing
To test the different approaches a basic model setup is used in which multiple variables can be changed. Figure 3-1 shows the setup used in the theoretical part of the UNIBEST study. It consists of three groynes with a length (L) of 250 meters from the original coastline. The groynes are placed along a straight coastal stretch and are 250 meters apart (B).

L and / or B can be changed to assess the influence of the groyne separation distance and the groyne length.

![Figure 3-1: Basic model setup](image-url)
**Bathymetry**

UNIBEST-CL+ is a single line modelling software package. This means that it does not change the cross-shore profile shape, only the coastline. Every climate point generated with UNIBEST-LT uses a fixed bathymetry and this one remains the same during the calculations. It only progresses and regresses with the movement of the shoreline.

In all scenarios tested, the bathymetry remains the same along the entire coast. This means all the grid points get assigned the same cross-shore profile. The profile used in the theoretical models is an equilibrium Dean profile.

\[ d = A x^{2/3} \]  \hspace{1cm} (2.1)

With:

- \( d \) = Depth [m]
- \( A \) = Sediment scale parameter, to be related to sediment size or fall speed (Dean, ibid)
- \( A = (1.04+0.086^\text{ln}(D_{50}))^2 \)  \hspace{1cm} (2.2)
- \( X \) = Cross-shore distance
- \( D_{50} \) = Median diameter of the particle size distribution [mm]

\[ \text{Figure 3-2: Three variations of the Dean Equilibrium Profile} \]

As can be seen in Figure 3-2, different profiles are used for different grain sizes. The profiles used are all three variants of the Dean Equilibrium profile.

<table>
<thead>
<tr>
<th>( D_{50} ) [mm]</th>
<th>A</th>
<th>Steepness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>0.2</td>
<td>0.0946</td>
</tr>
<tr>
<td>Steep</td>
<td>0.7</td>
<td>0.1724</td>
</tr>
<tr>
<td>Gentle</td>
<td>0.05</td>
<td>0.0355</td>
</tr>
</tbody>
</table>
Offshore Wave Climates
To test the sensitivity of the different approaches in different test scenarios, seven different wave climates are used. The climates Northwest (Single Direction), Northwest (Multiple Directions) and Symmetrical are created twice. Once with moderate conditions ($H_s = 1.2m, T_p = 8s$) and once with more severe conditions ($H_s = 2m, T_p = 12s$). For the 'Realistic Climate' only one North Sea wave climate is used.

Table 3-2: Offshore wave climates

<table>
<thead>
<tr>
<th>Climate</th>
<th>Hs [m]</th>
<th>Tp [s]</th>
<th>Dir [deg]</th>
<th>Nr Conditions</th>
<th>Wave rose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest, Single Direction (NSD)</td>
<td>2</td>
<td>12</td>
<td>320°</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.2</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northwest, Multiple Directions (NMD)</td>
<td>2</td>
<td>12</td>
<td>270°-360°</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.2</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symmetrical, Multiple Directions (SMD)</td>
<td>2</td>
<td>12</td>
<td>270°-90°</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.2</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Realistic, Multiple Directions (RMD)</td>
<td>Reduced Realistic North Sea Climate</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All climates are first applied in a Delft3D-WAVE model as a boundary condition. Delft3D-WAVE is then used to generate all the wave conditions around the test scenario of three groynes (Figure 3-3). The output of these models is then used in all three different approaches, so all approaches work with the same base conditions.
For the Automated or Manual approach the Delft3D-WAVE output is used to collect the global climate conditions and to get the wave conditions at the tip of the groynes. The white starred locations in Figure 3-3 indicate the locations at which data is collected that is used as input for the Kamphuis calculations.

Position Local Climates
One of the sub questions of this research is to check the importance of the positioning of the local climates. In UNIBEST-CL+, local climates can be introduced between structures to model the sheltered, reduced climate. The Automated approach, at this moment, only can place the local climates at the shoreline. But is that the best location? For this reason, it is decided to assess the importance of the cross-shore position of the wave climate locations on coastline changes (See Figure 3-4).

Three possible locations / situations are tested (Figure 3-4).

- At the shoreline (Location 1)
- Half way the groyne (Location 2)
- At the edge of the transport zone between the groyne (Location 3)
Model discretisation
Besides the previous mentioned physical parameters, UNIBEST-CL+ also uses some
important numerical / model parameters, like the spatial grid and the model duration.

Spatial Grid
To calculate the coastline change UNIBEST-LT calculates a cross-shore transport
distribution. The UNIBEST-CL module uses this distribution to calculate at every grid line the
change of the coastline. (Figure 3-5)

Figure 3-5 shows the grid (\(\Delta x\)) used in the UNIBEST-CL calculations. The first 50 meters
around the groynes, the grid spacing is 5 meters. Between 50 and 200 meters and between
300 and 450 meters the grid spacing is 15 meters. The difference in spacing is made
because of the more detail close to the groyne that is created in this way.

Model duration
The model calculation time of the UNIBEST-CL module is set to 5 years. This is done to be
certain to reach the equilibrium state of the coastline in each of the model runs. Most runs
reach the state of equilibrium after calculating around 2 to 2.5 years. The time step (\(\Delta t\)) used
in all the model runs is 1/100 year.

Other physical parameters
UNIBEST-CL+ uses, besides the earlier mentioned input parameters, several other variables.
Unlike the previous, they are kept to the default value of UNIBEST or they are kept zero.

- Current
  The longshore current is set to zero to rule out the influence of it.
- Transport parameters
  These are kept at the default values of UNIBEST-CL+. The formulae used are those
  of van Rijn (2004). The sediment parameters (\(D_{50}\)) are adjusted, according to Table
  3-1, to be representative for the bottom profile, because a steeper profile corresponds
  with courser grains.
- Wave parameters
  These are kept at the default values of UNIBEST-CL+. The parameters represent the
  breaking and bottom friction. A linear wave-current interaction model was used.
3.3 Modelling scheme
The previous mentioned parameters are combined to several modelling runs. The runs 101-107 are based on the normal profile, runs 111-117 are based on the steep profile and 121-127 are based on the more gentle profile. Table 3-3 shows the different combinations of profiles and wave conditions.

<table>
<thead>
<tr>
<th>Runs</th>
<th>Bottom</th>
<th>Hs [m]</th>
<th>Tp [s]</th>
<th>Dir [deg]</th>
<th>Nr Conditions</th>
<th>Wave condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>Normal</td>
<td>2</td>
<td>12</td>
<td>320</td>
<td>1</td>
<td>Northwest, Single Direction (NSD)</td>
</tr>
<tr>
<td>111</td>
<td>Steep</td>
<td>1.2</td>
<td>8s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>121</td>
<td>Gentle</td>
<td>2</td>
<td>12</td>
<td>270-360</td>
<td>8</td>
<td>Northwest, Multiple Directions (NMD)</td>
</tr>
<tr>
<td>105</td>
<td>Normal</td>
<td>1.2</td>
<td>8s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>115</td>
<td>Steep</td>
<td>2</td>
<td>12</td>
<td>270-90</td>
<td>10</td>
<td>Symmetrical, Multiple Directions (SMD)</td>
</tr>
<tr>
<td>125</td>
<td>Gentle</td>
<td>1.2</td>
<td>8s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>102</td>
<td>Normal</td>
<td>2</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>112</td>
<td>Steep</td>
<td>1.2</td>
<td>8s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>122</td>
<td>Gentle</td>
<td>2</td>
<td>12</td>
<td>270-90</td>
<td>10</td>
<td>Symmetrical, Multiple Directions (SMD)</td>
</tr>
<tr>
<td>104</td>
<td>Normal</td>
<td>2</td>
<td>12</td>
<td>270-90</td>
<td>10</td>
<td>Symmetrical, Multiple Directions (SMD)</td>
</tr>
<tr>
<td>114</td>
<td>Steep</td>
<td>1.2</td>
<td>8s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>124</td>
<td>Gentle</td>
<td>1.2</td>
<td>8s</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.4 Modelling approaches
During this study, three approaches of coastline modelling near structures in UNIBEST-CL+ will be elaborated and compared to each other. The approaches used are:

- ‘Manual Kamphuis’ approach
- ‘Automated Kamphuis’ approach
- ‘SWAN’ approach

The different approaches all look at the diffraction and sheltering processes behind a coastal structure. The way in which this is taken into account, within coastline change computations, differs.
The 'Manual Kamphuis' approach
This approach is based on the fact that the modeller calculates local wave climates in the shadow zone of a structure, apart from the modelling software. Often the formulations of Kamphuis (1998) are used for the calculation of shielding and diffraction. It is a rather easy computation that is suitable for irregular wave patterns. 

The coefficient for wave height reduction (K_d) can be obtained by using the formulations in Table 3-4. The wave height at the specific location in the sheltered area can be obtained by multiplying the reduction coefficient with the wave height at the tip of the groyne structure. The wave direction at the sheltered point depends on the blockage of the structure, while the wave period is assumed to remain unchanged. The newly created wave climate can be implemented manually in the UNIBEST-CL+ program at a local climate point.

Table 3-4: Kamphuis formulations

<table>
<thead>
<tr>
<th>K_d formula</th>
<th>Conditions</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0093θ + 0.000025θ²</td>
<td>0 ≥ θ ≥ -90</td>
<td>(2.3)</td>
</tr>
<tr>
<td>0.71 + 0.37 sinθ</td>
<td>40 ≥ θ ≥ 0</td>
<td>(2.4)</td>
</tr>
<tr>
<td>0.73 + 0.17 sinθ</td>
<td>90 ≥ θ ≥ 40</td>
<td>(2.5)</td>
</tr>
</tbody>
</table>

Figure 3-6: Basics of the Kamphuis formulations
• The ‘Automated Kamphuis’ approach
  In this approach the local wave climates in the sheltered area close to the structures are calculated automatically by the UNIBEST-CL+ modelling software. In fact it is very similar to the ‘Manual Kamphuis’ approach. It also uses the Kamphuis formulations to calculate the reduced climate, but it is automatically evaluated by the UNIBEST-CL+ model. Because it is embedded in UNIBEST the total calculation time is strongly reduced, and it is less labour intensive for the modeller. The advantage of this model is also that a large number of local climates can be computed at different distances from the structure. The Automated approach calculates a local climate at every grid cell alongshore. This results in a significant number of wave climates in the sheltered area, which should give an accurate representation.

  It is noted that the local climates can be generated only for locations at the shoreline. In this approach, it is also assumed that a flat bottom, from the tip of the groyne to the position of the local climate, is present. Currently there is no possibility to change these parameters. The approach therefore implicitly assumes that a flat bed (i.e. no refraction and wave breaking) and diffraction for the whole profile, as if it is as sheltered as at the shoreline. It is, however, expected that this approach can still provide reasonable good results. One of the tasks during this study is to find out if the assumptions are acceptable.

• The ‘SWAN’ approach
  The third approach uses the Delft3D-WAVE model to generate the local climate points in the shadow area of the structure. Delft3D-WAVE creates nearshore wave climate conditions on the basis of an offshore wave climate and bathymetrical information. The Delft3D-WAVE model uses the SWAN model (using wave-energy transport) to compute the wave transformation towards the shore and the processes that influence the waves. It is expected that this results in more accurate nearshore wave climate conditions than the other approaches, but it will also take the modeller more time to set up the modelling. First of all, a Delft3D-WAVES model needs to be set up, it needs to run the calculation and finally the wave information should be imported in the coastline model. To reduce the time required for this procedure, UNIBEST-CL+ has the option of extracting wave data from the Delft3D output files at specific locations. These local climates again can be used to calculate shoreline changes in the vicinity of the groyne structures.

  Using Delft3D-WAVE can be very useful to get detailed local climates if only offshore data is available. The downside of an approach with wave data from Delft3D is that the UNIBEST model can only handle one climate condition at the seaward side of the profile, and thus only sheltering and diffraction conditions that are representative for this location. In reality the wave sheltering may differ over the cross-shore profile from very significant at the shoreline to hardly any effect on the seaward side. Within UNIBEST it is not possible, using this approach, to put the wave climate close to or at the shoreline because in Delft3D the wave breaking will have dissipated all wave energy. This results in the absence of any wave energy at the shoreline.

  The above shows the Automated approach should be fast, but the Delft3D approach is expected to be more accurate (when used at locations at some distance from the coastline because of the energy dissipation due to wave breaking). The goal is to compare the outcome of the different approaches and see if they can match each other by changing the model details. Finally the applicability of the Automated module should be clear at the end of the study.
3.5 Model results

After running the models the output files are transformed to figures with the use of Matlab to visualise the results. Different conditions are compared to check the applicability of the approaches mentioned in the previous section. In this section the output of both (1) the investigation into coastline changes near the structure and (2) the influence of the positioning of the local climate points on the effective width will be elaborated.

3.5.1 Model Output

All the models, after running both LT and CL modules, result in a file representing the coastline change. By combining the results of the different approaches and locations, but with the same wave conditions, in one figure, a good comparison can be made (See for example Figure 3-8). This comparison of the different approaches is done by looking at the equilibrium coastline changes close to the groyne structure. However, besides the coastline orientation (shown in figures) also the displacement of the coastline is of importance. This numerical information is therefore shown in tables below the figures.

The comparisons in this report are performed separately for the North West (NMD), Symmetrical (SMD) and Realistic (RMD) climates (See Table 3-3). Appendices B and C contains more detailed images and observations of the conditions considered in this section.

3.5.2 Model observations

The model results (in Appendix B and C) show typical behaviour that is characterized by the following observations:

- All conditions show accretion on the left side of the structure.
- The conditions coming from the northwest (NSD, NMD) show erosion on the right side of the groyne.
- The symmetrical conditions (SMD) show accretion on the right side of the groyne, (nearly) equal to the accretion on the left side.
- The manual approach with local climate conditions at the shoreline gives in almost all runs quite the same result as the Automated approach. The are some small differences at the groyne concerning the coastline angle.
• When local climate conditions are derived at the positions ‘half way’ the groyne field, the coastline curvature for the SWAN approach is less pronounced than for the Manual approach with local climates at the same locations.
• Similar, the SWAN approach gives less pronounced coastline curvature than the Manual approach for local climates that are placed at the edge of the transport zone (i.e. at the depth of closure).
• When, for the symmetrical climate, the local climates are placed at the edge of the transport zone, the coastline curvature for the Manual or the SWAN approach is very small. The relative difference between the approaches is therefore exaggerated.
• The coastline shape in the shadow zone of groynes can be very similar for (1) runs with a large wave and steep profile and (2) runs with a moderate wave and moderately steep profile (see run 107 and run 113). It is noted that these runs have a symmetrical wave climate.
• The runs with multiple conditions from the northwest show on the left side of the groynes rather the same coastline change for all approaches except for the SWAN approach with local climates half way the groyne field. (and SWAN at the coastline for run 116)
• The SWAN approach with local climates at the edge of the transport zone, with positions close to the shore line result in significant less coastal change compared to the approaches using Kamphuis.

3.6 Results analysis
The previous section showed the specific results in the output of the model tests. These results can, most of the time, be related to physical processes. In some cases, however, the result should be attributed to numerical parameters or model imperfections. This section will elaborate the observations made in section 3.5.2. Not all observations will be dealt with separately. Some observations are returning at multiple conditions, mostly with the same reason.

• Implementation of the Automated approach.
• Effect of dominant wave direction.
• Effect of wave breaking.
• Effect of refraction.
• Situation with a symmetrical climate.
• Width of the transport zone w.r.t. the groyne length.

Implementation of the Automated approach
On average, the results of the Manual 1 and Automated calculations are similar. This is a good indication that the Automated module in UNIBEST works well for this (test) situation. Chapter 4, about the field case at Sitges, will make clear if it is also suitable for a not standard, semi-symmetrical situation.
The differences in the coastline angle near the groyne that are visible between the Manual approach with local climates at the shoreline (i.e. Manual 1) and the Automated approach (Auto), can be explained by the fact that the automated by the fact that the automated approach calculates a local climate at every cross-shore ray. In this case that is every 5 m for the area up till 50 meters from the groyne and every 15 meters for the rest of the coastline. The manual calculations calculate every 25 meters a local climate point. This means the automated approach has more local climate input locations.
Effect of dominant wave direction
Some situations with obliquely incoming waves from one direction (e.g. run 102 with a normal profile and high waves from the North-West) show that the SWAN 2 approach (with locations half way the groyne length) results in less coastline change compared to SWAN 3 (with local climates at the edge of the transport zone). The actual curvature of the coastline, however, is larger for the SWAN3 approach. It is expected that an approach with wave climate locations at rather offshore locations (e.g as for SWAN 3) result in an underestimation of the coastline curvature for situations with dominant wave conditions from one side.

Effect of wave breaking
The effect of wave breaking is expected to be of relevance for the speed at which coastline changes will take place. This was not directly derived from the models, as an equilibrium coastline was studied, but it is expected that wave breaking reduces the coastline curvature for very mildly sloped beaches as the energy at the shoreline is less. Furthermore, it is expected that the approaches using the Kamphuis formulation (i.e. Manual and Automated approach) may overestimate the coastline curvature slightly. As the Kamphuis formulation assumes a flat bed, from the tip of the groyne towards the local climate point. This means there is no interaction between the waves and the bottom and therefore there is no wave breaking. These Kamphuis approaches do not lose wave energy due to breaking. The effect is illustrated by run 116 which shows the coastline, as result from the local climate points at the edge of the transport zone close to the shore line (SWAN3) less curved compared to the Automated and Kamphuis resulting coastline.

Effect of refraction
Another effect of this flat bed is the fact no bottom refraction is present from oblique incoming waves. In the Kamphuis approaches there is no refraction calculated from the tip of the groyne towards the local climate point due to the assumed flat bottom. SWAN on the other hand does calculate refraction towards the local climate point. Therefore not only is the distance of coastline change but also the coastline angle smaller for the SWAN approach than the Kamphuis approaches. The effect is illustrated by run 106 which shows the difference between the SWAN and Manual calculation, both with local climate points half way the groyne. The SWAN approach does calculate the effect of refraction towards this location, the Kamphuis approach does not. This results in a coastline that is much more flat for the SWAN approach.

Situation with a symmetrical climate
Runs with symmetrical wave climates (e.g. run 103) showed that the SWAN approach at the edge of the transport zone (SWAN3) resulted in less coastline change and smaller coastline curvature than the SWAN approach with local climates half way the groyne field (SWAN2). This is caused by the fact that the edge of the transport zone is almost at the line between the two groyne tips, which results in an underestimation of the effect of the structures on the wave climates. Furthermore, the simulations with symmetrical climates resulted in very symmetrical coastline shapes (because of the symmetricallity of the climate). The net transport generated by this climate is very small. It is therefore expected that gross transports (generated by a temporary wave condition) can in reality become very important, while they are not directly accounted for in the model as it uses the net-climates.
Width of the transport zone w.r.t. the groyne length

When the local climates are laying almost at the seaward edge of the groyne field, all approaches underestimate the diffraction effect. The shielding of the groyne towards these points is expected to be underestimated, so too little changes in the wave climate conditions do take place. This will result in a less curved coastline between the groynes than may be expected in reality. However, when the local climates of the SWAN approach are taken at or too close to the coastline (Location 1), like run 116 and 117, the magnitude of the wave conditions for the SWAN approach is underestimated. Wave energy is dissipated for a large part already due to coastal processes like wave breaking etc. This results in a smaller transport distribution, less transport and less coastline change compared to what would happen in reality. The approach with the Kamphuis formulation (Manual or Automated) does not suffer from the energy loss near to the coast, but has the drawback that processes like refraction are not accounted for.

An interesting observation is that runs with high waves and steep profiles (e.g. Runs 106 and 107) provide similar results as runs with moderate waves and normal profile steepness (e.g. Runs 112 and 113). The reason for this is that the locations of the edge of the transport zone are identical for these runs. The location where waves ‘feel’ the bottom is similar for the moderate wave height on a ‘normal’ slope and for the high wave height on a steeper slope. In this case it is accidental that during run 107 and 113 location 2 and 3 are identical. This shows that an important parameter for the classification of coastline stretches with groynes is the ratio between groyne length and the width of the transport zone.

3.7 Conclusions theoretical study

Based on the results of the theoretical study, a table is made about the usability of the different approaches (Table 3-6). A distinction is made between four different situations which together represent the situations of the theoretical study. These situations are based on the ratio between the width of the transport zone and the length of the groyne as can be seen in Table 3-5.

<table>
<thead>
<tr>
<th>Table 3-5: Ratio width of the transport zone divided by groyne length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport zone width / Groyne length</td>
</tr>
<tr>
<td>--------------------------------------</td>
</tr>
<tr>
<td>20%</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>50%</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>80%</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>≥100%</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

The different approaches are scored in two criteria (Table 3-6). First, the resulting coastline shape is evaluated. Second, the transport magnitude is assessed for each approach. The scores are based on the comparison of the different ratios for each approach. If an approach gives excellent result for a certain ratio, it is scored with ‘+++’, if the result is average the score will be ‘0’ and if it gives poor results the score will be ‘--’. Therefore, the scores are not quantitative but qualitative. So if the ratio does not score higher than a 0, it means it does not give an optimal result for that specific approach, but the results of the other approaches are even worse in that situation.
Table 3-6: Usability of different approaches

<table>
<thead>
<tr>
<th>Width transport zone divided by Groyne length</th>
<th>Coastline Shape</th>
<th>Transport Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>+</td>
<td>+/0</td>
</tr>
<tr>
<td>50%</td>
<td>+</td>
<td>+/0</td>
</tr>
<tr>
<td>80%</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>100% (and larger)</td>
<td>0</td>
<td>0/-</td>
</tr>
</tbody>
</table>

Future modelling of coastal situations can be based on this table. In a certain situation first it should be know how much the transport zone extends in cross-shore direction. Using this data and the length of the groyne, the previous mentioned ratio can be determined. By using Table 3-6, the best suitable approach can be chosen by looking at the highest score for that ratio.

Using the table above, some conclusions can be drawn on when to use the different approaches:

- The automated approach works well, compared to the manual Kamphuis calculations. The results can even be slightly more detailed than the manual Kamphuis calculations with local climates at the shoreline, because of the use of more local climate points.
- The SWAN method with the local climate points at the edge of the transport zone seems to be the best approach in situations where the transport zone is relatively small compared to the groyne length (e.g. 20%). The distance from the edge towards the local climate point is rather long. Therefore several processes, for instance sheltering, are taken into account over a longer distance, resulting in more realistic results. If the edge of the transport zone is located more seaward, closer to the tip of the groynes, the distance over which the processes are calculated in SWAN, becomes less. This means the effect of sheltering becomes less and the wave height at the local climate points remains too high.
- When the edge of the transport zone is located further seaward, the use of the automated Kamphuis approach becomes more interesting. Because it is calculating the local climate points at the shoreline, the effect of diffraction and sheltering is included fully in the approach. The downside of this approach is the fact no refraction is taken into account because the Kamphuis approach assumes a flat bottom towards the local climate point. The approach may therefore yield less accurate results than the SWAN approach for situations with a small ratio of transport zone width over groyne length (e.g. 20%).
- Using Kamphuis with local climate points half way the groynes results in less effect of diffraction because the distance from the tip of the groyne towards the local climate point is smaller. The positive side of this approach would be the little effect of refraction, taken into account from the local climate point towards the shoreline (in UNIBEST-CL). The use of the Kamphuis approach with local climate points at the shoreline is preferred above this method in most of the situations.
3.8 Sensitivity analyses

Additional research is done on specific aspects of the applied model setup. With the use of separate Delft3D and UNIBEST-CL+ models several parameters are varied and tested on their importance. The next paragraphs will investigate the following questions:

- Is the cross-shore position of the local climate point of influence on the magnitude of the alongshore transport?
- Is the length of the cross-shore profile used in UNIBEST-LT relevant for determining the cross-shore transport distribution?
- What is the influence of set-up on the local coastline changes?

3.8.1 Cross-shore profile vs. cross-shore local climate position

During the preliminary model runs the positioning of the local climates along the edge of the transport zone raised some questions about the correctness of the locations compared to the profile length. Therefore further investigation is done into width of the transport zone in UNIBEST modelling. What is the relation between the used profile length and the position of the local climates between the groynes?

To be sure the position of the local climate point is correct, the influence of the position of these points should be examined. The output files of UNIBEST-LT contain data about the width of the coastal zone in which 90% of the transport takes place. But the transport is depending on the bathymetry profile. Not only on the profile itself but also on how far the profile extends of shore. Therefore, it is important how the profile (extension) is chosen compared to the position of the local climate.

Three tests are developed for this.

- A fixed profile length of 750 meters where the position of the local wave climate is changed depending on the depth (at 2-7 meters depth) (Figure 3-9)
- At a fixed depth of three meters, the profile length in UNIBEST-LT is changed from the location of the three meter depth to 750 meters offshore (Figure 3-10).

Is the cross-shore position of the local climate point of influence on the magnitude of the alongshore transport?

The profile length, specified in UNIBEST-LT, is kept at a fixed length of 750 meters. The location of the local climates between the groynes is varied from the position of 2 meters depth until the position with a depth of 7 meters.

![Figure 3-9: Cross-shore transport distribution at variable locations of the local climate points offshore and with a fixed profile in UNIBEST-LT of 750m](image-url)
Figure 3-9 shows the results of this test. The lines are the contour lines showing the longshore transport at the specific depths. Between the groyne lengths (length is 250 meters) the transport builds up from the shadow zone. But when the local climate locations are further offshore than the length of the groyne, the transport becomes uniform and doesn’t change very much further offshore. This indicates that the locations of the local climates must lay between the groynes.

Is the length of the cross-shore profile used in UNIBEST-LT relevant for determining the cross-shore transport distribution?

The position of the local climate point is kept at a fixed depth of three meters (200 meters offshore). This is well inside the enclosed area between the groynes. In this test the profile length, chosen in UNIBEST-LT to calculate the cross-shore transport distribution, is varied from 200 meters offshore to 750 meters offshore. The orange/yellow line in Figure 3-9 is the same location and same depth as the dark blue line in Figure 3-10.

![Figure 3-10: Cross-shore transport distribution at a fixed distance (fixed depth of 3 m) offshore with a variable profile length in UNIBEST-LT](image)

The lines in Figure 3-10 again represent the longshore transport magnitude. Looking at those lines, there is minimal difference in transport magnitude. This indicates that the length of the profile, used in UNIBEST-LT, is not of much influence on the calculations.

Both previous test are finally combined in one model to verify the previous findings. The length of the depth profile, used in UNIBEST-LT, extends towards the point where the local climate is positioned.

![Figure 3-11: Cross-shore transport distribution with a profile length (in UNIBEST-LT) equal to the offshore distance of the local climate point](image)
The result, Figure 3-11, shows almost the same figure as the results of the first test. Again we see the transport magnitude between the groynes grow from the shadow zone to the unsheltered area. Seaward of the groyne field the contour lines are parallel again.

**Conclusion on importance transport zone width**

It is important where to place the local climate points, if they have to be related to the width of the transport zone. To take the effect of the shadow zone into account it is important to place them in between the groynes, inside the groyne field. The length of the profile, used in UNIBEST-LT, to calculate the cross-shore transport distribution, is of less importance. Also with a profile length as far as three times the groyne length, used at all the locations, the difference is minimal. But for the most correct and accurate outcome, the length of the used profile should extend until the position of the local climate point.

### 3.8.2 What is the influence of set-up on the local coastline changes?

Chapter 0 already did describe the process of set-up driven currents between two structures. This section will describe the possibility to implement such a current in a single line model, UNIBEST-CL+. The calculations with the UNIBEST-CL+ module are based on the cross-shore transport distribution calculated with UNIBEST-LT and the coastline change calculated with UNIBEST-CL, based on the outcome of the LT module. These software modules do not take into account setup driven transport. In line with this study this would be setup driven current in the shadow zone of a structure. But how important is this current compared to the other input of the model?

Therefore some testing is done to include setup driven current into the UNIBEST modelling.

**Model setup**

For this sensitivity study, the SWAN and UNIBEST models from the main investigation are used. Besides this UNIBEST and SWAN calculations, a model extension is made with Delft3D. This model includes both Delft3D WAVE and FLOW calculations that are coupled together. By doing this the currents between the groynes can be simulated. The velocities and directions of these currents are then used in UNIBEST-LT simulating the setup driven current. This is done by implementing a tide into the local climate points, generated halfway the groyne length. In this way they do not only represent the reduced wave climate but also a current due to a fictive tide. Each climate condition is coupled with the current that is generated by it. So, one wave condition drives one ‘sub’ current. With UNIBEST-LT the cross-shore transport distribution is calculated again, this time with current contribution. This output is used again in a UNIBEST-CL calculation. Finally the comparison is made between the outcome of the original model (without the current) and with the current included. This is done for both the coast angle at the groynes and the cross-shore change of the coastline.

![Figure 3-12: Local climate locations set-up driven current model](image)
Table 3-7: Wave climate conditions set-up driven current model

<table>
<thead>
<tr>
<th>Input</th>
<th>Test 1</th>
<th>Test 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hs₀ [m]</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Tp₀ [s]</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Dir [deg]</td>
<td>North East Multidirectional</td>
<td>Symmetrical</td>
</tr>
</tbody>
</table>

**Delft3D results**

Both Figure 3-13 and Figure 3-14 show the output of one of the wave conditions calculated (Hs=2m, Tp=12s, Dir=280deg).

Figure 3-13 shows the water level set-up and Figure 3-14 gives the depth averaged velocities of the same condition. As expected the maximum set-up is generated in the right, less protected corner of the groyne field. This generates a current from right to left between the groynes. The mirrored condition (Dir=70deg) of course results in (almost) the same result, but with a flow in the reversed direction.

All the conditions between these two generate a setup that is shifting from highest set-up on the right side to highest set-up on the left side, with setup contour lines parallel to the shoreline at Dir=360 deg.

Over all the conditions the maximum of the water level set-up lays around the 10 cm above the normal waterline. This results in a maximum current velocity of about 0.7m/s.

Looking at the conditions that are symmetrical around the shore normal (10deg vs. 350deg, etc.), the setup and velocities are not exactly the same. There are minor differences. The reason for this is the way the two groyne fields are influencing each other. Processes in one groyne field can influence the processes in the other groyne field (Eddies, rip currents around the structures, etc.). The effect of the non-similarity in velocities will have an effect on the results of the UNIBEST calculations.

**UNIBEST-CL+ results**

As stated earlier, the output of Delft3D is implemented into the UNIBEST model. Figure 3-15, Figure 3-16 and corresponding tables show the result after both the UNIBEST-LT and –CL calculations. To increase the visibility of the results, both figures are zoomed in.
Figure 3-15: Coastline change generated by a Symmetrical climate, with and without set-up driven current

Table 3-8: Coastline change generated by a Symmetrical climate, with and without set-up driven current

<table>
<thead>
<tr>
<th>Symmetrical</th>
<th>Distance [m]</th>
<th>Angle [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Middle L</td>
</tr>
<tr>
<td>With current</td>
<td>5.3</td>
<td>4.2</td>
</tr>
<tr>
<td>Without current</td>
<td>5.4</td>
<td>5.1</td>
</tr>
<tr>
<td>Difference</td>
<td>0.1</td>
<td>0.9</td>
</tr>
<tr>
<td>Percentage</td>
<td>2%</td>
<td>23%</td>
</tr>
</tbody>
</table>

Figure 3-16: Coastline change generated by a Northwest climate, with and without set-up driven current

Table 3-9: Coastline change generated by a Symmetrical climate, with and without set-up driven current

<table>
<thead>
<tr>
<th>Northwest</th>
<th>Distance [m]</th>
<th>Angle [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Middle L</td>
</tr>
<tr>
<td>With current</td>
<td>-23.0</td>
<td>28.2</td>
</tr>
<tr>
<td>Without current</td>
<td>-24.5</td>
<td>30.4</td>
</tr>
<tr>
<td>Difference</td>
<td>1.5</td>
<td>2.2</td>
</tr>
<tr>
<td>Percentage</td>
<td>6%</td>
<td>8%</td>
</tr>
</tbody>
</table>
Both the symmetrical and the Northwest climate show very little differences between the calculation with and without the implementation of the current. The maximum difference in distance is around 2 meter; the maximum angle difference is just less than one degree. Looking at the percentages, a difference of 20% in coastal distance seems quite a lot, but based on a small coastline change, this difference is still not very large. Comparing the two climates, the Northwest climate has a larger coastline change, but the percentage is smaller than the Symmetrical climate. Most of the percentages are below 10% resulting in small coastline changes of about 1 meter and coast angle differences of 0.5 degree.

Conclusion on set-up driven currents
The implementation of a set-up driven current in UNIBEST-CL+ has just a very small impact on the result of coastline change. This particular situation (combination of wave height, period, bathymetry and groyne configuration) does not generate enough current to be significant enough. On this scale it costs quite some time to create the necessary models (SWAN, Delft3D and UNIBEST) and the result with UNIBEST, finally, has minimal additional value compared to calculations without the added current. Therefore none of the main model tests is repeated with set-up included.
4 Field application case, Sitges, Spain

4.1 Introduction
To test the previous found results, a test case is made located at Sitges, Spain. Sitges is situated at the east-northeast coast of Spain, directly at the Mediterranean Sea. The combination of the coast configuration of Sitges and the Mediterranean Sea climate make this location ideal for testing and comparing the results from previous sections. This chapter will describe the location of the field case. Afterwards it will elaborate the making of the model in Delft3D WAVE and UNIBEST-CL+. Finally the results will be discussed.

4.1.1 Location description
City of Sitges
Sitges (Catalan pronunciation: [siˈdʒes], Catalan for silos) is a Spanish town about 35 kilometres southwest of Barcelona. Located between the Garraf Massif and the sea, it is known for its beaches, nightspots, and historical sites. Today, Sitges’ economy is based on tourism and culture offering more than 4,500 hotel beds, half of them in four-star hotels. Most of the hotels and tourism attraction are situated at one of the 17 beaches.¹

Figure 4-1: Sitges, Spain

Beaches
Many of the Catalan beaches are losing sand due to the transport rate of the longshore drift and cross-shore (rip) currents. The longshore drift at the coastal stretch of Sitges is not sufficient to resupply the lost sediment. Therefore several measures are taken to keep the sand as much as possible at its place, to keep the beaches where they are at the moment. A lot of the local income is coming from tourism, so keeping the beaches is a key issue.

For the testing of the UNIBEST-CL+ module this can be an interesting case, because of the use of multiple groyne structures close together, used to protect the coast. Besides hard measures also soft measures are used, like nourishments. At first the model will be set up to the north western part of the beach area because of the rather straight coastline and the use of just the normal groynes.

¹ Source: http://en.wikipedia.org/wiki/Sitges
4.2 Model Input

4.2.1 Bathymetry

The bathymetry used in this model is based on a cross-shore profile at the coast of Sitges. This profile is extruded along the entire coast of the Sitges area (Table 4-1 and Figure 4-2).

Table 4-1: Bathymetry Sitges, Spain

<table>
<thead>
<tr>
<th>Cross-shore distance [m]</th>
<th>Depth [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>-1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-30</td>
<td>1</td>
</tr>
<tr>
<td>-105</td>
<td>2</td>
</tr>
<tr>
<td>-135</td>
<td>3</td>
</tr>
<tr>
<td>-185</td>
<td>4</td>
</tr>
<tr>
<td>-290</td>
<td>5</td>
</tr>
<tr>
<td>-1215</td>
<td>10</td>
</tr>
<tr>
<td>-3915</td>
<td>20</td>
</tr>
<tr>
<td>-5805</td>
<td>30</td>
</tr>
</tbody>
</table>

4.2.2 Groyne configuration

The coast of Sitges is protected by multiple coastal structures. To the south there is a lot of diversity in the type of construction used. They used T-head groynes, L-head groynes, natural small islands and shore parallel breakwaters to protect the coastline. More to the north there are mainly shore normal breakwaters. This area is the most interesting for the use in this study. Figure 4-3 gives an overview of the model area.

There are five groynes on a rather straight coastal stretch. The sixth groyne, furthest on the right, is placed perpendicular to a curve in the coastline. Therefore it is not in line with the other five. The part between the first five groynes is very similar to the theoretical study in the previous chapters. The outcome is expected to be rather similar to the outcome of this theoretical study. The area between the first two groynes on the right is a more difficult area. Because of the curved coastline this area might cause some problems because the cross-shore rays, perpendicular to the coastline, are crossing each other in this area.
4.2.3 Offshore wave conditions

Sitges is situated close to the city of Barcelona. South of Barcelona, Spanish research organisations placed several buoys (Waverider) to record wave data along the Catalonian coastline. One of them (Llobregat) is situated the closest to the city of Sitges and is close enough to use as representable data for this test case (Figure 4-4).

Figure 4-4: Position of the offshore wave climate

This specific buoy makes recordings every 20 minutes. By processing the data, a yearly record is reduced to a climate containing ten conditions. These ten conditions give a reasonable representation of the wave conditions in front of the coast of Sitges (Table 4-2 and Figure 4-5).

These conditions are used to create a wave model with Delft3D WAVE. This model calculates the near shore wave conditions. The SWAN approach uses the results of this model to collect the wave data at the local climate points, specified in UNIBEST. Besides that, the Kamphuis calculation approaches (both Automated and Manual) use the model results to gather the wave information at the tip of the groyne that is used as input for the Kamphuis calculation method.

Figure 4-5: Schematised wave climate Sitges
Table 4-2: Wave conditions, Mediterranean Sea, Representable for the coast of Sitges

<table>
<thead>
<tr>
<th>Hsig [m]</th>
<th>Period [s]</th>
<th>Alfa</th>
<th>Duration [days]</th>
<th>Hsig [m]</th>
<th>Period [s]</th>
<th>Alfa</th>
<th>Duration [days]</th>
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<td>5.3</td>
<td>128.4</td>
<td>1.3</td>
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</tr>
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<td>5.7</td>
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<td>3.8</td>
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<td>5</td>
<td>1.119</td>
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<td>202.9</td>
<td>2.9</td>
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<td>16</td>
<td>1.34</td>
<td>5.4</td>
<td>201.3</td>
<td>1.7</td>
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<td>13.7</td>
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<td>5.7</td>
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<td>1</td>
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<td>5.3</td>
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<td>0.7</td>
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<td>112</td>
<td>2.8</td>
<td>0.371</td>
<td>3.3</td>
<td>222.9</td>
<td>10.7</td>
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<td>3.6</td>
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</tbody>
</table>
4.2.4 Local climates

The results of the previous chapter are used to determine the approach of the field case. For this field case study only two of the three modelling approaches will be examined. The first one to be examined is the Automated approach. Secondly the SWAN approach will be used. The local climate points of the Automated approach will lay again on the coastline, like in the theoretical study. At every grid line it will produce a local, climate depending on the climate at the tip of the groyne at the right side of the groyne field. For the SWAN approach, several locations are picked by hand. These locations are laying close to the line half way the groyne tip and the coastline (See the purple dots in Figure 4-6).

![Figure 4-6: Global and Local climate positions of SWAN approach (including offshore wave climate, Section 4.2.3)](image)

The green line in Figure 4-6 indicates the original coastline. The purple dots between the groynes are the local climate points for the SWAN approach and the other two, more offshore, purple points are the global climates. They are used in both SWAN and Automated approach.

4.2.5 Model parameters

UNIBEST-LT parameters

To calculate the transport distribution, ‘van Rijn 2004’ is chosen. Table 4-3 shows the parameters that are used as input for this calculation.

<table>
<thead>
<tr>
<th>Table 4-3: Transport parameters UNIBEST-LT</th>
<th>Table 4-4: Wave parameters UNIBEST-LT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport parameters</td>
<td>Wave parameters</td>
</tr>
<tr>
<td>Formula</td>
<td>van Rijn 2004</td>
</tr>
<tr>
<td>D10     [µm]</td>
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</tr>
<tr>
<td>D50     [µm]</td>
<td>210</td>
</tr>
<tr>
<td>D90     [µm]</td>
<td>290</td>
</tr>
<tr>
<td>Dss     [µm]</td>
<td>210</td>
</tr>
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<td>Sediment density [kg/m³]</td>
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<tr>
<td>Seawater density [kg/m³]</td>
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<tr>
<td>Porosity</td>
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<tr>
<td>Temperature [°C]</td>
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<tr>
<td>Salinity [ppm]</td>
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<td>Current-related suspended transport factor</td>
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<td>Current-related bed load transport factor</td>
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</tr>
<tr>
<td>Wave-related suspended transport factor</td>
<td>1</td>
</tr>
<tr>
<td>Wave-related bed load transport factor</td>
<td>1</td>
</tr>
</tbody>
</table>
UNIBEST-CL parameters

The spatial grid of the coastline model of the calculations at Sitges is shown in Figure 4-7.

Every groyne section contains about 16-22 grid lines, depending on the complexity of the coastline at that location. In the curvature on the right side, a more dense grid is used (smaller $\Delta x$) because of the complexity of the coastline at that location.

According to the model duration of the theoretical study and the results found in that study, a model duration for Sitges is chosen of 2 years. The resulting coastline after that time probably will not reach equilibrium because this specific coastline loses sediment, and therefore will keep changing its shape. The time step ($\Delta t$) used in the Sitges model is 1/100 year.

4.3 Model results

After running both SWAN and UNIBEST-CL+ models, for the SWAN approach and the Automated approach, Figure 4-8 shows the result of the coastline changes.

Figure 4-8: Model results of SWAN and Automated approach
The background photo shows the situation at Sitges at the end of the year 2010. The red and the blue line represent the results of the Automated approach respectively of the SWAN approach. Clearly the area on the right shows extreme, not realistic results for the SWAN results. The Automated approach shows a more accurate, realistic result in this right groyne segment. The other groyne fields show very similar results comparing the two approaches and each field has rather the same result for the SWAN approach and for the Automated approach. The groyne field on the left has a little more coastline change compared to the SWAN result.

Both the resulting coastlines from the SWAN and Automated approach are rather straight coastlines between the groynes, perpendicular to the average, offshore, wave direction. At the groynes there is just some very small change of the angle.

4.4 Analyses and conclusions

The fact that both SWAN and Automated give quite similar results indicates the Automated model now also works rather well in a field case situation. The small differences between the two approaches can be explained by the fact that the Automated approach uses about three times more local climates to calculate the local transport. Besides that, it also calculates diffraction over a longer distance compared to the SWAN approach. Because the main wave direction already is rather shore normal, the effect of diffraction is not to be expected very large. By taking the local climate points for the SWAN approach half way the groyne length, the diffraction taken into account becomes very small.

However, both approaches do not result in a coastline that is very similar to the background photograph of Sitges in 2010. This might have several reasons. First of all, the wave climate. The used climate is a schematised wave climate, generated from a time series of measurements. These measurements are taken every 20 minutes, during one year. It is possible that not all conditions are taken into account very well due to this reduction of conditions. Besides, because the measurements are just from one year, some more severe conditions, like once in five or ten year storms, are not taken into consideration. Secondly, the accuracy of the model can be the case. By increasing the number of gridlines close to the groynes, the number of local climates increases. This results in more input data and will result in a more detailed outcome close to the groyne. Furthermore, the bathymetry can have significant influence on the coastline change. The interaction between the incoming waves and the bottom does effect the transport of sediment close to the shore. During this study, because of the lack of detailed bathymetry information, only one cross shore profile is used during the UNIBEST calculations. By gaining more bottom information, more detailed profiles can be made, resulting in a better representation of the local bottom profile. Another explanation can be found in the difference between net and gross transport between the groynes. Every wave condition generates a certain current between the groynes. Some going from 'left to right', others from 'right to left'. These result in a gross sediment transport in each direction. Summed together they give the net sediment transport magnitude and direction. But the modelling of the gross transports might give different results compared to the real situation. The current from the groyne towards the centre of the groyne starts already at its full magnitude (it is there or it is not). But in reality, it builds up. The further away from the groyne the larger the current becomes. And because of the smaller current closer to the structure, the amount of sediment taken from there is less compared to the amount calculated in the model. More sand remains at the structure and results in a more curved coastline. Finally, there is the fact that the groynes not seem to block all the longshore transport. At some of the groynes, bypassing seems to be present, resulting in sediment transport from one coastal cell to the next. At the end of the coastal stretch, this will result in the loss of sediment of this part of the coastline. In reality, the coast of Sitges is indeed loosing sand. The import of sediment, partially from a river close by, is lower than the export of sediment. Therefore the beaches need extra supply of sand, realised by nourishments. The result of this is not easy to recreate in a model like UNIBEST. More information is needed on the sediment import and export of the coastal stretch.
4.5 Sensitivity analyses Sitges

The results from the field case study are satisfying because of the fact that the Automated approach works well, compared to the SWAN approach. On the other hand, the result of both approaches differs quite a lot from the original coastline, as can be seen in the background. There are several possible causes that can explain this rather large difference. The first that would be logical is the use of an incorrect wave climate. The used wave climate is a schematised climate, based on a time series recording of one year. This schematisation can result in climate with, on average, a small deviation from the original climate. Therefore, in this sensitivity analyses, several comparisons are made with small adjustments to the original, schematised climate, to see if this gives any improvement of the results.

The following adjustments are made:

- Based on the original schematized climate, a climate is created with an addition of 20 degrees to all the wave directions.
- Based on the original schematized climate, a climate is created with a threshold on the wave height of 1.5 meters. This value is based on a cross-shore distance that just remains in the groyne field. Over this distance it is supposed that the coastal transport does not generate bypassing of the groynes. The value of the wave height is calculated using the depth at this distance and the breaker index (Equation (1.12)).
- Based on the original schematized climate, a climate is created with an addition of 45 degrees to all the wave directions.
- Based on the original schematized climate, a climate is created with an addition of 45 degrees to all the wave directions and a threshold on the wave height of 1.5 meters.

![Figure 4-9: Coastline changes of different wave climates during sensitivity analyses Sitges.](image)

Besides the four variants discussed, Figure 4-9 also shows the coastline change of the original used wave climate. It can be seen that the differences are minimal. The average coastal angle differs a little between the different runs, but the coastline shape remains quite the same.
Still, the curvature of the coastline close to the groynes is not like it should be according to the background photo. Clearly, the wave climate is not the main cause to this outcome. There should be another cause that explains the shape of the coastline. (The causes discussed further on in this chapter are not tested in new analyses.)

Looking at the physical model input, like the wave climate, also the bottom profile can have its influence on the final coastal shape. The foreshore has quite a lot influence on the behaviour of the waves. In this field case, one cross-shore profile is used, based on previous studies. This cross-shore profile is used along the entire coast of Sitges. There is the possibility that this foreshore profile is not correctly modelled in SWAN and UNIBEST, resulting in a coastline that is different from reality. Also, the assumption of one type of sediment on the entire Sitges coastal profile can be of influence. Because the whole profile is assumed to have just a sandy bottom a lot more sediment can be transported, compared to the possible situation of a rockier bottom further offshore. In reality, the municipality of Sitges needs to nourish the beaches every few years, because this stretch of coast is losing sand. The waves and currents are transporting more sand away from the coast compared to what they supply. This is something that is not accounted for in the Sitges model. Finally, besides the physical aspects, the result of the Sitges model can be caused by some model imperfections. In reality, return currents from the groyne, towards the centre of the groyne field, need time and space to build up. So close to the groyne, the current is still small and does not take away much sediment. In UNIBEST it is assumed, the current is already at strength close to the groyne, taking away more sand close to the groyne. This results in less coastal change in the model, compared to the real situation.

To optimise the result of the Sitges model, the arguments stated above, can be examined. But the main goal of the field case was, to determine whether or not the Automated Kamphuis approach works well in a real situation. This seems to be the case, compared to the existing SWAN approach. Therefore the field case will not be elaborated further.
5 Conclusions and Recommendations

5.1 Conclusions

This section will provide the final conclusions based on the results found in the previous two chapters, Theoretical Study and Field Application Case Sitges.

During this study two different models are created. First a theoretical model is made, based on a simple situation of three groynes, perpendicular to a straight coastline. This model was used to answer two questions:

- How does the Automated Kamphuis approach perform compared to manual Kamphuis calculations and SWAN calculations?
- Which modeling approach is suitable for what kind of conditions?

Theoretical studies

During the theoretical study several physical input parameters are varied to simulate different kind of situations. Two different bottom profiles and different wave conditions are used. The wave conditions are used to create three different wave climates, supplemented by a fourth, realistic climate. Combining these input parameters resulted in multiple model runs, each calculated with the three approaches (Automated and Manual Kamphuis and SWAN) at three different locations (At the shore line, half way the groyne length and at the edge of the transport zone). The SWAN model, made to generate data to extract for the SWAN approach, is based on the same physical parameters.

The following shows the conclusions that are made based on the theoretical study:

- The different input parameters resulted in situations that could be classified by the ratio of width of the transport zone compared to the length of the groyne. By analyzing the results, based on this table and the use of the different approaches, the usability of the different approaches is found.
- The Automated Kamphuis approach functions well in this simple environment, compared to the manual Kamphuis approach. The resulting coastline shape is even a little better, because of the use of more local climates, resulting in more detailed input for UNIBEST-CL+.
- The usability of the different approaches strongly depends on the ratio of the width of the transport zone compared to the length of the groyne. The SWAN approach takes into account more shallow water processes, like wave breaking and refraction. But putting the local climate point, gathered with the SWAN approach, further offshore underestimates the impact of sheltering of the coastal structures. Therefore, the SWAN approach is best to be used when the previous mentioned ratio is small (e.g. 20%), because there is the maximum sheltering calculated and also refraction and wave energy dissipation are calculated well. When the ratio is larger (up to 80-90%) it is better to use the Automated approach, with local climate points at the shoreline. Although this approach does not calculate the wave refraction it does include the maximum wave diffraction behind the structures. Besides that, the Automated approach is less labour intensive to create and takes less time to run.
In reality, there are not much situations where such long groynes are created that the ratio becomes in the order of 20%. The ratio is more in the range of 50-90%. Therefore, in a lot of situations it will be favorable to use the Automated approach.

- Based on the sensitivity analyses, it can be concluded that the placing of the local climate points between the groynes is important. Outside the groyne field no changes in the transport profile are visible. The length of the profile that corresponds with a local climate, in UNIBEST-LT, is of less importance. This means that for the different local climate positions the same (length of the) profile can be used.

- The second sensitivity analyses show that the implementation of the set up driven current in the specific situation of the theoretical study does not contribute very much to the change of the coastline. Therefore, in similar situations, the current created by this set up can be left out of the model. This results in significant less modeling time, because there is no need to create an extra Delft3D hydrodynamic model.

- Both approaches, Automated and SWAN, have their imperfections. The reality probably will be laying between the result of both approaches.

Field Case
The second model that is made is the field case of Sitges. The main question about the field case is whether or not the Automated approach performs well in field cases. To answer this question, again both a SWAN and UNIBEST-CL model are made. During the field case test only the SWAN and Automated Kamphuis approaches are tested. After overcoming some imperfections of the Automated approach (tweaking the model during the model testing) now this approach gives similar results as the results of the SWAN approach. Still there are some small differences, but that has the same reason as in the theoretical study.

- The fact that SWAN and Automated Kamphuis are providing rather the same result indicates the Automated approach will work well in field case situations. The differences can be explained by the fact that the coarseness of the coastal grid determines the number of local climate positions in the Automated approach. The SWAN approach uses manually selected locations for the local climate and, because of the labour intensity, there will be less locations compared to the Automated approach. Besides the number of local climate positions, also the fact that Kamphuis underestimates certain processes contributes to the small difference between the two approaches.

- The model results, compared to the areal photograph, differ quite a lot from the photo of the real situation. The average coastline angle is comparable, but the coastline angle close to the structures is clearly different. Therefore some sensitivity analyses are done, mainly to see whether or not the reduction of the climate may be representing the wrong wave conditions. Several different wave climates are used but on average all of them gave the same result.

- There are several other explanations for the lack of coastline curvature. A possible explanation can be the simplified cross-shore profile. The bathymetry used in this study is based on just one cross-shore profile. The bathymetry of the foreshore has significant influence on the energy reduction and change of direction of the waves. Another possibility is the fact that in reality the beach area suffers a lot of sediment loss. More sediment is taken away by the current than the current takes towards the beach area. The municipality of Sitges has to nourish the beaches every few years. This is not taken into account in the used model. Finally the model doesn’t replicate the all coastal processes as it should. The current, created by certain waves, that flows from the groyne towards the middle of the groyne field, is assumed to be there already at the groyne structure. In reality it builds up, and becomes stronger towards the middle of the groyne field. Because it is weaker at the structure less sediment is taken away over there and this results in leaving more sand behind, resulting in a more curved coastline.
Related to the longshore currents, also eddy like currents are not taken into account, while they can be expected in the situation of Sitges.

These last possible explanations are not further elaborated in this study. The goal of the field case was to see whether or not the Automated approach would function well in a realistic situation. Compared to the SWAN approach, that is proven to give reasonable result, it does. The fact that the coastline of Sitges is not represented correct has to do with model (input) imperfections. This is not essential for the outcome of this study, but can be investigated in another research.

5.2 Recommendations

Based on the research done during this study and the results the study produced, some recommendations about further, more extensive investigation will be made in this section.

- Future model creation can be based on the table scoring the different approaches, looking at the ratio between the width of the transport zone and the groyne length.
- This study has been performed for a mild wave climate with minimal tidal influence. To be able to use the different approaches in a wider variety of conditions the effect of tide can be investigated.
- The field case model should be performed on a situation of which there is more detailed information available. The information of physical parameters at Sitges was limited, resulting in a not accurate coastline change.
- A more versatile coastal stretch should be investigated. The coastal stretch of Sitges is rather straight, with just at the end a small curve in it. The question rises whether or not the model will perform as it should in the case of a more capricious coastline.
- This study is focused on the performance of the Automated model in the case of 100% impermeable, (shore normal) groyne structures. It might be interesting to see if the approach is also capable of dealing with longshore breakwaters or breakwaters that are partially permeable.
- Adding the possibility to the Automated approach of placing the local climate points at a distance off shore that is a percentage of the groyne length.
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Appendices

A Theoretical background

A.1 Introduction
This appendix will provide some theoretical background to the research done in this report. It will describe the principle of 1D modelling, some analytical solution for processes close to structures and some about the shallow water transitions.

A.2 1-D modeling
The single line model (1-D model) in essence solves two simple equations:
The equation of conservation of mass (the 1-D Morphological equation)

\[
\frac{\partial Q}{\partial x} + D \frac{\partial y}{\partial t} = 0
\]  

(A.1)

and the equation of motion (a bulk sediment transport rate expression, no detailed fluid flow relationships)

In the morphological equation the assumption is made that the beach profile remains constant in shape during erosion and accretion; a movement of a constant profile over a depth equal to the depth of closure, below which is assumed there is no more sediment moving activity. Alongshore there can be a lot of different shapes of the beach profile, as long as they all move in cross-shore direction without a change of shape. All the contours move at the same rate and, by that, can be represented by a single contour line.

Figure A-1: Principle of single line modelling (1D)
The equation of conservation of mass in this situation will result in:

\[ \frac{\partial \psi}{\partial t} = - \frac{1}{(h_b + h_c)} \left( \frac{\partial Q}{\partial x} - q_c \right) \]  

(A.2)

in which \( h_c \) represents the closure depth, \( h_b \) the berm height, \( q_c \) the cross-shore losses and \( Q \) the bulk longshore transport.

If this longshore transport is continuously the same value, no changes in the shoreline will occur. But when the longshore sediment transport rate is not zero anymore erosion or accretion will take place.

The longshore sediment transport rate essentially is a representation of all flow and sediment interaction parameters.

One of the functions that is used very often is the CERC formulation for sediment transport (SPM, 1984).

\[ Q_c = K_c H_{sb}^{2/3} \sin 2\alpha_b \quad [m^3/y] \]  

(A.3)

\( K_c \) is a constant including fluid and sand density and porosity. \( H_b \) is the breaking index, \( \alpha_b \) is the angle of breaking.

A more extensive version of this formula is created by Kamphuis (1991) including separate effects of wave height, wave period, wave steepness, beach slope and grain size. This formula is created after extensive model testing and finally based on measured \( H_s \). He indicated with this study also that for breaking wave height a Rayleigh distribution can be assumed.

\[ \frac{Q}{\rho H_{sb}^3} = 1.3 \times 10^{-3} \left( \frac{H_{sb}}{L_{op}} \right)^{1.25} m_b^{0.75} \left( \frac{H_{sb}}{D_{50}} \right)^{0.25} \sin^{0.6} (2\alpha_b) \quad [kg/s] \]  

(A.4)

This can be converted to:

\[ Q_k = 6.4 \times 10^4 H_{sb}^2 T_p^{1.5} m_b^{0.75} D_{50}^{-0.25} \sin^{0.6} (2\alpha_b) \quad [m^3/y] \]  

(A.5)

(with the use of \( Q_k = \frac{Q}{(\rho_c - \rho)(1 - p)} \))

\( T_p \) is the peak period, \( m_b \) is the slope trough the breaker zone, \( D_{50} \) the median grain size, \( p \) is the porosity of the sand.

It can be seen the sediment transport rate is proportional to \( H^2 \).
The previous equations assume there is no longshore gradient in wave height. If this is the case, for instance behind structures, as a first estimate the wave angle term should be changed to:

\[ \sin 2\alpha_b - K \frac{1}{m_b} \cos \alpha_b \frac{\partial H_{sb}}{\partial x} \]  

(A.6)

\( K \) is a coefficient that has a value between 1 and 2, suggested by Hanson and Kraus (1989)

Several more sediment transport formulae are developed in time, by different people, that can be used to calculate the longshore sediment transport in a 1-D model. Depending on the available parameters and demanded output, a choice can be made between the different formulations. Table A-1 shows the different input parameters and some remarks.

Table A-1: Input parameters different transport formulae

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Variable</th>
<th>Formula</th>
<th>parameter</th>
<th>Value</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D_{10} )</td>
<td>10^th percentile grain diameter [( \mu \m)]</td>
<td>( W_s )</td>
<td>Sediment fall velocity [m/s]</td>
<td></td>
<td>depends on sediment</td>
</tr>
<tr>
<td>( D_{50} )</td>
<td>median grain diameter [( \mu \m )]</td>
<td>( D_{50} )</td>
<td>90^th percentile grain diameter [( \mu \m )]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( m_b )</td>
<td>median stone diameter [( \m )]</td>
<td>( W_s )</td>
<td>Sediment fall velocity [m/s]</td>
<td></td>
<td></td>
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<tr>
<td>( D_{50} )</td>
<td>median grain diameter [( \mu \m )]</td>
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<td>( D_{50} )</td>
<td>median grain diameter [( \mu \m )]</td>
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<td>( m_b )</td>
<td>median stone diameter [( \m )]</td>
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<td>( W_s )</td>
<td>Sediment fall velocity [m/s]</td>
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<td>Sediment fall velocity [m/s]</td>
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</tbody>
</table>
A.3 Analytical solution of shoreline change close to a structure with diffraction included.

Because of the varying wave height through the shadow zone also the sediment transport will vary in this area. There are multiple ways to calculate the influence of the shadow zone on the transport of sediment in the shadow region. One of them is shortly explained below. It is possible to imagine that the incident breaking wave angle is a continuous function of $x$.

\[ \alpha_0 = x \alpha_m / B \quad \text{If the angle of incidence at the groyne is zero. (A.7)} \]

\[ \alpha_0 = \alpha_v + (\alpha_H - \alpha_v) \frac{x}{B} \quad \text{If the angle at the groyne is not zero. (A.8)} \]

The retrieved, coupled system is containing two solution areas, one inside the shadow zone, one outside with a boundary at the jetty represented by

\[ \frac{\partial y_1}{\partial x} = \tan(\alpha_v) \quad (A.9) \]

According to Larson et al. (1987) the analytical solution is:

\[
y_1(x, t) = \frac{(\alpha_H - \alpha_v) \epsilon t}{B} \left[ 2i^2 \text{erfc} \left( \frac{B - x}{2\sqrt{\epsilon t}} \right) + 2i^2 \text{erfc} \left( \frac{B + x}{2\sqrt{\epsilon t}} \right) - 1 \right] \\
- \tan(\alpha_v) \left[ 2 \sqrt{\frac{\epsilon t}{\pi}} e^{-\frac{x^2}{\epsilon t}} - x \text{erfc} \left( \frac{x}{2\sqrt{\epsilon t}} \right) \right] \quad (A.10)
\]

for $t > 0$ and $0 \leq x \leq B$ and

\[
y_2(x, t) = \frac{(\alpha_H - \alpha_v) \epsilon t}{B} \left[ 2i^2 \text{erfc} \left( \frac{x + B}{2\sqrt{\epsilon t}} \right) - 2i^2 \text{erfc} \left( \frac{x - B}{2\sqrt{\epsilon t}} \right) \right] \\
- \tan(\alpha_v) \left[ 2 \sqrt{\frac{\epsilon t}{\pi}} e^{-\frac{x^2}{\epsilon t}} - x \text{erfc} \left( \frac{x}{2\sqrt{\epsilon t}} \right) \right] \quad (A.11)
\]

for $t > 0$ and $x > B$.

With:
- $\alpha_0$ = angle between breaking wave crest and coordinate axis
- $\alpha_H$ = breaking wave angle in illuminated zone
- $\alpha_v$ = breaking wave angle at groyne
- $B$ = length of shadow region, lee side of the groyne
- $i^2 \text{erfc}$ = $n^\text{th}$ integral of the complementary error function
- $\epsilon$ = diffusion coefficient $= \frac{Q_0}{D}$
- $Q_0$ = longshore sand transport rate
- $D$ = Depth of closure

For the scope of this study, these equations are too complicated, and extensive. Instead, use is made of the diffraction formulations of Kamphuis.
A.4 Shallow water transition

Using a single line model (1-D), requires the use of simple wave computations, because of the many repetitive computations.

Assumed is a single wave approaching the shore.

The wave is a deep-water wave with wave height $H_0$ and a peak period $T_p$. But to calculate sediment transport breaking wave conditions are needed:

$$H = K_S K_R K_D H_0$$  \hspace{1cm} \text{(valid until breaking)} \hspace{1cm} (A.12)$$

$K_S = $ Shoaling coefficient $K_S = (C_{g0} / C_g)^{1/2}$ \hspace{1cm} (A.13)

$K_R = $ Refraction coefficient $K_R = \cos \alpha / \cos \alpha$ \hspace{1cm} (A.14)

$K_D = $ Diffraction coefficient $K_D$ depends on the location in the diffracted area (and on the ratio Wave length versus obstacle length)

$C_g$ is the Group velocity, $\alpha$ is determined by the use of Snells law:

$$\sin \alpha = \frac{C}{C_g} \sin \alpha_0$$ \hspace{1cm} (A.15)

Simultaneously a breaking criterion must be solved. Introduced by Kamphuis (1991):

$$H_{sb} = 0.095 e^{4mL_{p0}} \tanh(k_{p0}d_h)$$ \hspace{1cm} (A.16)

$L$ and $k$ refer to the peak of the wave spectrum.
B Results

B.1 Introduction
This appendix shows the results of the theoretical study in more detail. Each of the runs is examined separately and the observations are given per run. Appendix C will provide the larger figures for each run.

B.2 Results per run
Northwest, Multiple Directions (NMD)
The results of the coastline changes for all the modelling approaches of model run 102 are shown in Figure B-1 and Table B-1:

![Figure B-1: Coastline change at the structures, run 102, detail at centre groyne](image)

<table>
<thead>
<tr>
<th>Run 102</th>
<th>Distance [m]</th>
<th>Angle [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left Middle L Middle R Right</td>
<td>Left Middle L Middle R Right</td>
</tr>
<tr>
<td>Manual 1</td>
<td>-28    41    -28 41</td>
<td>5.1 20.4 5.1 20.4</td>
</tr>
<tr>
<td>Manual 2</td>
<td>-36    44    -36 44</td>
<td>9.9 21.1 9.9 21.1</td>
</tr>
<tr>
<td>Manual 3</td>
<td>-40    45    -42 45</td>
<td>13.7 20.4 16.4 20.4</td>
</tr>
<tr>
<td>Automated</td>
<td>-27    41    -27 41</td>
<td>3.1 20.5 3.1 20.5</td>
</tr>
<tr>
<td>SWAN 2</td>
<td>-25    35    -25 34</td>
<td>3.8 16.1 3.7 16.0</td>
</tr>
<tr>
<td>SWAN 3</td>
<td>-35    42    -37 42</td>
<td>8.0 19.1 11.1 19.0</td>
</tr>
</tbody>
</table>

There are some clear differences between the approaches visible but also some similarities.
- Manual 1 and Automated give quite the same result. There is just a small difference between the coastline angles on the unsheltered side of the groynes.
- On the not sheltered side of both groynes (the left side) all seven approaches result in the rather the same coastline angle and coastal distance. The distance is within a 7.5% difference and the angle even within a 5% range. Except for the SWAN2
calculation. Both the distance and angle differ about 25% with the other average distance and angle.

- On the right side of the groynes, in the sheltered area, there is a significant difference visible. The results of the local climates further away from the shore (location 2 and 3) show almost 25% more retreat than the points at the shoreline.
- On the sheltered side of the groyne the result of the SWAN2 and Manual1 and Automated are very similar, with a little smaller coast angle for SWAN2.
The results of the coastline changes for all the modelling approaches of model run 106 are shown in Figure B-2 and Table B-2:

![Figure B-2: Coastline change at the structures, run 106, detail at centre groyne](image)

**Table B-2: Coastline change and coast angle at the structures, run 106**

<table>
<thead>
<tr>
<th>Run 106</th>
<th>Distance [m]</th>
<th>Angle [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>Middle L</td>
<td>Middle R</td>
</tr>
<tr>
<td>Manual 1</td>
<td>-26</td>
<td>40</td>
</tr>
<tr>
<td>Manual 2</td>
<td>-36</td>
<td>45</td>
</tr>
<tr>
<td>Manual 3</td>
<td>-34</td>
<td>45</td>
</tr>
<tr>
<td>Automated</td>
<td>-26</td>
<td>41</td>
</tr>
<tr>
<td>SWAN 2</td>
<td>-24</td>
<td>34</td>
</tr>
<tr>
<td>SWAN 3</td>
<td>-23</td>
<td>34</td>
</tr>
</tbody>
</table>

![Table B-2](image)

Figure B-2 and Table B-2 show the results of a wave direction between 270deg and 360deg (Symmetrical Climate).

There are some distinct differences between the previous discussed run 102 and this one.

- The starred locations, at the edge of the transport zone are positioned closer to the shoreline. They partially are at the same place as the locations half way the groyne length (The coloured dots indicate location 2).
- The results of all three approaches of location 2 and location 3 are very similar, except a small difference in the shadow zone.
- There is a difference between the results of SWAN- and Manual 2 and SWAN- and Manual 3. The difference in distance is in the order of ten meters, the coast angle difference is around 4 degrees.
The results of the coastline changes for all the modelling approaches of model run 112 are shown in Figure B-3 and Table B-3.

![Figure B-3: Coastline change at the structures, run 112, detail at centre groyne](image)

![Table B-3: Coastline change and coast angle at the structures, run 112](image)

<table>
<thead>
<tr>
<th>Run 112</th>
<th>Distance [m]</th>
<th>Angle [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Middle L</td>
</tr>
<tr>
<td>Manual 1</td>
<td>-27</td>
<td>40</td>
</tr>
<tr>
<td>Manual 3</td>
<td>-31</td>
<td>43</td>
</tr>
<tr>
<td>Automated</td>
<td>-27</td>
<td>41</td>
</tr>
<tr>
<td>SWAN 2</td>
<td>-35</td>
<td>52</td>
</tr>
<tr>
<td>SWAN 3</td>
<td>-25</td>
<td>44</td>
</tr>
</tbody>
</table>

Run 112, represented by Figure B-3 and Table B-3, is very similar to run 102. The difference between the two runs is the bathymetry. Run 112 is based on the steep Dean profile (See Figure 3-2).

- The first thing to notice is that width of the transport zone, indicated by the starred dots, is again a lot smaller than run 102 (Figure B-1). This time they lay even more shore ward than location 2.
- The coastline angle of SWAN 3, in the shadow zone, is minimal.
- The coast angle of Manual 1, Manual 3 and Automated in the shadow zone is similar.
- The unsheltered side shows identical coast angle for Manual 2 and 3 and for Automated and Manual 1.
- SWAN 2 has more coastline change and a larger coastline angle than the other run.
The results of the coastline changes for all the modelling approaches of model run 116 are shown in Figure B-4 and Table B-4.

![Coastline change at the structures, run 116, detail at centre groyne](image)

**Table B-4: Coastline change and coast angle at the structures, run 116**

<table>
<thead>
<tr>
<th>Distance [m]</th>
<th>Angle [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
</tr>
<tr>
<td>Manual 1</td>
<td>-28</td>
</tr>
<tr>
<td>Manual 2</td>
<td>-38</td>
</tr>
<tr>
<td>Manual 3</td>
<td>-31</td>
</tr>
<tr>
<td>Automated</td>
<td>-28</td>
</tr>
<tr>
<td>SWAN 2</td>
<td>-23</td>
</tr>
<tr>
<td>SWAN 3</td>
<td>-13</td>
</tr>
</tbody>
</table>

Run 116, Figure B-4 and Table B-4, is in fact a combination of run 106 and 112. It has the less severe wave runs and also it uses the steeper Dean profile.

- The starred dots, the edge of the transport zone, lay very close to the shoreline.
- SWAN 3 shows clearly less coastline change and smaller coastline angle compared to the other approaches.
- The results of Manual 3 are close to Manual 1 and Automated, both in angle and distance.
- Also SWAN 2 shows less distance and angle than the Kamphuis approaches, but quite some more than the SWAN 3 approach.
Symmetrical, Multiple Directions (SMD)

The results of the coastline changes for all the modelling approaches of model run 103 are shown in Figure B-5 and Table B-5.

Figure B-5: Coastline change at the structures, run 103, detail at centre groyne

Table B-5: Coastline change and coast angle at the structures, run 103

<table>
<thead>
<tr>
<th>Run 103</th>
<th>Distance [m]</th>
<th>Angle [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Middle L</td>
</tr>
<tr>
<td>Manual 1</td>
<td>8.0</td>
<td>7.9</td>
</tr>
<tr>
<td>Manual 2</td>
<td>7.6</td>
<td>7.5</td>
</tr>
<tr>
<td>Manual 3</td>
<td>2.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Automated</td>
<td>8.2</td>
<td>8.3</td>
</tr>
<tr>
<td>SWAN 2</td>
<td>6.5</td>
<td>6.7</td>
</tr>
<tr>
<td>SWAN 3</td>
<td>2.1</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Run 103, Figure B-5 and Table B-5, are based on a symmetrical wave climate and normal Dean bottom profile.

- Looking at both figures above, it is clear that there is symmetry in the wave conditions. All 6 approaches do show this symmetry both in angle and distance.
- The results from the approaches with climates at the same location are rather the same. The largest difference is between the approaches at location 2.
- Strikingly, the coastal distance and angle of both Manual 3 and SWAN 3 are the smallest of all results. Compared to each other they are much alike but compared to the other approaches they are less than half the amount.
The results of the coastline changes for all the modelling approaches of model run 107 are shown in Figure B-6 and Table B-6.

Figure B-6: Coastline change at the structures, run 107, detail at centre groyne

Table B-6: Coastline change and coast angle at the structures, run 107

<table>
<thead>
<tr>
<th>Run 107</th>
<th>Distance [m]</th>
<th>Angle [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Middle L</td>
</tr>
<tr>
<td>Manual 1</td>
<td>8.4</td>
<td>8.4</td>
</tr>
<tr>
<td>Manual 2</td>
<td>8.2</td>
<td>8.2</td>
</tr>
<tr>
<td>Manual 3</td>
<td>8.2</td>
<td>8.2</td>
</tr>
<tr>
<td>Automated</td>
<td>8.5</td>
<td>8.7</td>
</tr>
<tr>
<td>SWAN 2</td>
<td>7.2</td>
<td>7.3</td>
</tr>
<tr>
<td>SWAN 3</td>
<td>7.2</td>
<td>7.3</td>
</tr>
</tbody>
</table>

Run 107 uses the same bottom profile as run 103, but the wave climate is based on a wave height of 1.2 meters instead of 2.0 meters.

- The first thing to notice is the fact that there are no starred dots in Figure B-6 which should indicate the locations at the edge of the transport zone. By coincidence they are laying half way the groyne length, the same as location 2.
- Manual 2 and 3, and SWAN 2 and 3, have the same results. This is due to the fact the local climates are at the same locations, half way the groynes length.
- Furthermore the angle and distance of both SWAN 2 and 3 are about 10-15% less than the other approaches.
The results of the coastline changes for all the modelling approaches of model run 113 are shown in Figure B-7 and Table B-7.

**Figure B-7: Coastline change at the structures, run 113, detail at centre groyne**

**Table B-7: Coastline change and coast angle at the structures, run 113**

<table>
<thead>
<tr>
<th>Run 113</th>
<th>Distance [m]</th>
<th>Angle [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Middle L</td>
</tr>
<tr>
<td>Manual 1</td>
<td>8.2</td>
<td>8.2</td>
</tr>
<tr>
<td>Manual 2</td>
<td>8.1</td>
<td>8.1</td>
</tr>
<tr>
<td>Manual 3</td>
<td>8.1</td>
<td>8.1</td>
</tr>
<tr>
<td>Automated</td>
<td>8.4</td>
<td>8.5</td>
</tr>
<tr>
<td>SWAN 2</td>
<td>7.2</td>
<td>7.2</td>
</tr>
<tr>
<td>SWAN 3</td>
<td>7.1</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Run 113 has the symmetrical wave climate with the heavier wave conditions (Hs=2m, Tp=12s). It is calculated with the steeper bathymetry.

- Like run 107, also run 113, shows no local climate points at the edge of the transport zone. They are at the same position again as the local climate points half way the groyne.
- Therefore the results of run 113 are almost the same as run 107. There are just some very small differences.
- The thing that also in these results comes forward is the difference between the approaches with the Kamphuis calculations and the SWAN approaches.
The results of the coastline changes for all the modelling approaches of model run 117 are shown in Figure B-8 and Table B-8.

### Figure B-8: Coastline change at the structures, run 117, detail at centre groyne

![Figure B-8](image)

### Table B-8: Coastline change and coast angle at the structures, run 117

<table>
<thead>
<tr>
<th>Run 117</th>
<th>Distance [m]</th>
<th>Angle [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Middle L</td>
</tr>
<tr>
<td>Manual 1</td>
<td>9.8</td>
<td>9.8</td>
</tr>
<tr>
<td>Manual 2</td>
<td>10.1</td>
<td>10.1</td>
</tr>
<tr>
<td>Manual 3</td>
<td>10.2</td>
<td>10.2</td>
</tr>
<tr>
<td>Automated</td>
<td>9.9</td>
<td>10.0</td>
</tr>
<tr>
<td>SWAN 2</td>
<td>9.0</td>
<td>9.1</td>
</tr>
<tr>
<td>SWAN 3</td>
<td>7.6</td>
<td>7.6</td>
</tr>
</tbody>
</table>

In line with the previous observations of the symmetrical climate conditions, run 117 shows the same characteristics. Run 117 is based on the steeper Dean profile and the milder wave conditions.

- Again the SWAN results are less than the other approaches.
- SWAN 3 is significantly less than the other six approaches.
- Manual 1, 2 and 3 are very close together.
- Location 3, the edge of the transport zone, is situated between Location 1 and 3, quite close to the shoreline.
The results of the coastline changes for all the modelling approaches of model run 104 are shown in Figure B-9 and Table B-9.

![Comparison of calculation methods - Run 104](image)

**Figure B-9: Coastline change at the structures, run 104, detail at centre groyne**

<table>
<thead>
<tr>
<th>Run 104</th>
<th>Distance [m]</th>
<th>Angle [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Middle L</td>
</tr>
<tr>
<td>Manual 1</td>
<td>2.2</td>
<td>20.9</td>
</tr>
<tr>
<td>Manual 2</td>
<td>1.8</td>
<td>20.7</td>
</tr>
<tr>
<td>Manual 3</td>
<td>1.2</td>
<td>19.2</td>
</tr>
<tr>
<td>Automated</td>
<td>3.2</td>
<td>20.7</td>
</tr>
<tr>
<td>SWAN 2</td>
<td>4.8</td>
<td>15.8</td>
</tr>
<tr>
<td>SWAN 3</td>
<td>3.0</td>
<td>15.8</td>
</tr>
</tbody>
</table>

Run 104 contains the calculation of the realistic climate on the normal bathymetry.

- It can be seen (Figure B-9) that the width of the transport zone is well within the area between the groynes; the groynes extend the width of the transport zone.
- SWAN 2 and SWAN 3 are identical at the left side of the groynes. On the right side SWAN 2 extends about 2 meters more seaward than SWAN 3. Also the angle is not the same at this side.
- Manual 1 and Automated are rather the same again.
- On the left side the distance resulting from SWAN is smaller than the other approaches, on the right side of the groyne SWAN results in larger offshore distance.
- Also the angle, resulting from the SWAN calculations, on the left side of the groyne is about 10% smaller compared to the other approaches.
The results of the coastline changes for all the modelling approaches of model run 114 are shown in Figure B-10 and Table B-10.

Figure B-10: Coastline change at the structures, run 114, detail at centre groyne

Table B-10: Coastline change and coast angle at the structures, run 114

<table>
<thead>
<tr>
<th>Run 114</th>
<th>Distance [m]</th>
<th>Angle [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Middle L</td>
</tr>
<tr>
<td>Manual 1</td>
<td>1.8</td>
<td>23.0</td>
</tr>
<tr>
<td>Manual 2</td>
<td>0.6</td>
<td>23.6</td>
</tr>
<tr>
<td>Manual 3</td>
<td>1.2</td>
<td>23.5</td>
</tr>
<tr>
<td>Automated</td>
<td>1.2</td>
<td>23.8</td>
</tr>
<tr>
<td>SWAN 2</td>
<td>4.7</td>
<td>20.6</td>
</tr>
<tr>
<td>SWAN 3</td>
<td>5.4</td>
<td>20.1</td>
</tr>
</tbody>
</table>

Run 114 has the same wave conditions as run 104. The difference compared to run 104 is the bathymetry. This calculation is carried out with the steep Dean profile.

- On the right side of the groyne there is a significant difference between the Automated and the Manual 1 approach, specifically the angle.
- The placing of the local climates at the edge of the transport zone is shifted shoreward a little, compared to run 104.
- On the left side again the SWAN resulting coastline lays closer to the shoreline compared to the other approaches.
- On the right side it is opposite to this; The SWAN coastline lays further seaward.
- On the left side of the groynes the approaches using Kamphuis, give results that lay close together, especially Manual 2 and 3.
C Output figures model runs

C.1 Explanation

The next pages show the results of the different model runs described in Table 3-3: Modelling Scheme. Each page gives the result of one of the conditions. The upper figure combines the results of all the modelling approaches and their different conditions. The lower three figures show each contain one of the approaches but with all their locations.
Comparison of calculation approaches - Run 101

Situation 1 = All three methods with the diffraction points at the coastline
Situation 2 = Manual and SWAN calculation with the diffraction points halfway the groynes
Situation 3 = Manual and SWAN calculation with the diffraction points at the edge of the 5% transport zone
Run 102: Waves, Multiple Direction, Hs= 2m, between 270-360deg

Normal Profile 06-Feb-2013

Deltanes / Boskalis

Diffracl Reflac

MSc Graduation Thesis: Coastline modelling with UNIBEST: Areas close to structures
Comparison of calculation approaches - Run 103

- Manual 1
- Manual 2
- Manual 3
- Auto 1
- SWAN 2
- SWAN 3
- Original Coastline
- Structure-L
- Structure-M
- Structure-R
- Local climate 2
- Local climate 3

Situation 1 = All three methods with the diffraction points at the coastline
Situation 2 = Manual and SWAN calculation with the diffraction points halfway the groin length
Situation 3 = Manual and SWAN calculation with the diffraction points at the edge of the 55% transport zone
Comparison of calculation approaches - Run 105

- Manual 1
- Manual 2
- Manual 3
- Auto 1
- SWAN 2
- SWAN 3
- Original Coastline
- Structure-L
- Structure-M
- Structure-R
- Local climate 2
- Local climate 3

**Situation 1**
- All three methods with the diffraction points at the coastline

**Situation 2**
- Manual and SWAN calculation with the diffraction points half way the groynes' length

**Situation 3**
- Manual and SWAN calculation with the diffraction points at the edge of the 95% transport zone
Run 106  Waves: Multiple Direction, Hs=1.2m, between 270-360deg

Comparing of calculation approaches - Run 106

Normal Profile  06-Feb-2013

Deltares / Boskalis

Difrac  Refrac
Comparison of calculation approaches - Run 107

- **Manual 1**
- **Manual 2**
- **Manual 3**
- **Auto 1**
- **SWAN 2**
- **SWAN 3**
- **Original Coastline**
- **Structure-L**
- **Structure-M**
- **Structure-R**
- **Local climate 2**
- **Local climate 3**

**Situation 1:** All three methods with the diffraction points at the coastline
**Situation 2:** Manual and SWAN calculation with the diffraction points half way the groin length
**Situation 3:** Manual and SWAN calculation with the diffraction points at the edge of the 95% transport zone
Comparison of calculation approaches - Run 112

Situation 1 = All three methods with the diffraction points at the coastline
Situation 2 = Manual and SWAN calculation with the diffraction points half way the grown length
Situation 3 = Manual and SWAN calculation with the diffraction points at the edge of the 05% transport zone
Situation 1 = All three methods with the diffraction points at the coastline
Situation 2 = Manual and SWAN calculation with the diffraction points half way the groin length
Situation 3 = Manual and SWAN calculation with the diffraction points at the edge of the 95% transport zone
Run 117 Waves: Multiple Direction, Hs=1.2m, between 270-90deg

Deltaris / Boskalis

Diffrac Refrac
D Software

D.1 Introduction
To get a good insight in the importance of the different processes, several software packages can be used. In this study four different software packages will be used:

- Matlab
- Delft 3D
- Muppet (based on Matlab)
- UNIBEST-CL+

Below, a brief explanation of the different packages will be given.

D.2 MATLAB 2012a

Basically MATLAB is a computing language, mostly used in technical application. It offers much functionality as algorithm development, data visualization, data analysis and numerical computations. MATLAB is applicable in a wide range of professions, from signal and image processing till computational biology.

The MATLAB language supports the vector and matrix calculations that are fundamental to engineering and scientific problems. In just a few lines it is possible to set up an algorithm because MATLAB is doing a lot of the background, basic work, such as variable declaring and allocating memory.

Also MATLAB is able to do iterative calculations in a simple and fast way by using processor optimized libraries and JIT compilation technology. It contains a lot of mathematical, statistical and engineering functions to support all common engineering and scientific operations based on linear algebra, Fourier transformations, ordinary and partial differential equations and many more.

Besides numerical computations, MATLAB offers a lot of functionalities for data analyses and data visualization. With MATLAB it is easy to open a lot of different data sources, like files, data bases and external devices. Using different tools MATLAB can perform several operations with these data sets:

- Interpolating / decimating
- Partially extraction
- Thresholds
- Correlation and filtering
- Matrix analysis
- eo

Finally MATLAB is very capable in visualizing data into 2D-3D graphs, video, presentations and other visual means. By creating an own GUI it is easy to access data from other programs and to create fast, often used graphical representations.

This last functionality is one that is often used at Deltares. They developed the GUI ‘QUICKPLOT’, an easy way to visualize the data gathered for other software, for instance Delft-3D and UNIBEST.

An more extended version of QUICKPLOT is Muppet, discussed later on.

In this study MATLAB mostly will be used to pre and post process data used in computational models like UNIBEST and Delft3D.
D.3 Delft-3D

**General**

Delft3D is a flexible integrated modeling program, which simulates two-dimensional (in either the horizontal or a vertical plane) and three-dimensional flow, sediment transport and morphology, waves, water quality and ecology and is capable of handling the interactions between these processes.

The suite is designed for use by experts and non-experts alike, which may range from consultants and engineers or contractors, to regulators and government officials, all of whom are active in one or more of the stages of the design, implementation and management cycle. The program can be used to calculate highly detailed processes in the coastal or river areas. Because the program is process based, most of the calculations take a lot of time. Therefore, the used time and, mainly, spatial scales are advised to be limited. It is possible to make calculations of years to centuries and of hundreds of kilometers but it would take a very long time to calculate.

**Features**

Some of the typical key features of Delft3D are:

- The suite gives direct access to state-of-the-art process knowledge, accumulated and developed at one of the world’s most renowned hydraulic institutes
- Very user friendly Graphical User Interface (GUI)
- All the programs within the suite have a high level of interactive possibilities

Delft3D suite consists out of several separate packages; D-Waves, D-Flow, D-Morphology, D-Water quality, D-Ecology and D-Particle tracking.

In this study the first is used the most, eventually combined with the second and third.

**D-Waves**

D-Waves computes the non-steady propagation of short-crested waves over an uneven bottom, considering wind action, energy dissipation due to bottom friction, wave breaking, refraction (due to bottom topography, water levels and flow fields), shoaling and directional spreading. The program is based on the spectral model SWAN. This model is a development of the Delft University of Technology, which is a close partner of Deltares in a number of research fields. For many decades, both institutes have been prominent in the field of wave modeling.

**D-Flow**

This program simulates non-steady flows in relatively shallow water. It incorporates the effects of tides, winds, air pressure, density differences (due to salinity and temperature), waves, turbulence (from a simple constant to the k-ε model) and drying and flooding. With the integrated heat and mass transport solver, Deltares’ front running knowledge of stratified hydrodynamics has been built into this program. The output of the program is used in all the other programmes in Delft3D suite.
D-Flow is the standard program and covers curvilinear and rectilinear grids, full 2D hydrostatic flow, temperature and substances, density driven flows, float (drogue) tracking, meteorological influences, on-line visualization and wave-current interaction. The D-Flow includes 3D flow and turbulence modeling, spherical grids, domain decomposition (connect multiple grids; refinement in both horizontal and vertical direction allowed), structures (weirs, gates, floating structures, semi-transparent structures) and horizontal large eddy simulations (sub-grid turbulence in horizontal).

**D-Morphology**
This program computes sediment transport (both suspended and bed total load) and morphological changes for an arbitrary number of cohesive and non-cohesive fractions. Both currents and waves act as driving forces and a wide variety of transport formulae have been incorporated.

The output of the Delft3D model (WAVE and FLOW) will be the base of this study.

**D.4 Muppet**
Muppet is a post processing tool developed by Deltares, based on MATLAB routines. By using Muppet it is rather easy to create a visible representation of the data outputted by Delft3D. It is possible to plot several output values together, subtracted or added up in different plot 'windows' on one sheet of paper.

Besides it has the advantage, above the standard post processing tool of Delft3D, QUICKPLOT, that it can store the layout one is using. With that, and some MATLAB script, very fast visualisations of several Delft3D runs can be created.

![Figure D-3: Muppet Interface](image)
D.5 **UNIBEST-CL+**

Within Deltares, UNIBEST-CL+ is developed. It is a powerful software package to model the longshore transports and coastline changes for both long time and spatial scales and smaller, more local problems.

As stated above, the cross-shore losses are not directly included in UNIBEST-CL+, but when combining it with the packages of UNIBEST-TC and UNISBEST-DC, also these processes can be assessed.

D.5.1 **Model set up**

UNIBEST-CL+ has the ability to model more complex coastal areas, non uniformly shaped, like bays, small island, curved coastlines etc. This is possible because of the use of a user defined reference line to which the shoreline changes are calculated.

D.5.2 **Processes**

The model itself requires quite a simple input regarding to wave conditions. The model itself can transform these wave conditions when entering the surf zone by using the Batjes-Stive model (1984) for wave propagation and decay of energy. In this model all the basic processes are taken into account. The most important are based on the loss of wave energy, like bottom friction, refraction, shoaling and wave breaking.

The influence of the rotation of the active part of the cross-shore profile on wave refraction is accounted for through an automatic determination of the dynamic boundary. The distribution of the longshore current along the coastal profile is derived from the depth-averaged momentum equation alongshore. A number of wave-current interaction models (Soulsby et al., 1993) can be used to compute the relevant bed shear stresses.

To compute the actual transport of sediment along the coast, several formulae are available:

- Transport of sediment vs wave energy (CERC, Kamphuis (1991))
- Gravel transport (vd Meer)

The respond of the model to the wave and current conditions is instantaneous, which means that is reacts immediately, not using time to reach the result. The transport calculated can be given in both the gross transport (two directions along the coast) and also the net, resulting transport.

An important concept in the coastal modeling is the relation between the sediment transport ($S$) and the coastline orientation ($\phi$). Given a constant wave climate, alongshore changes in the coastline cause gradients in longshore sediment transport, and with that new changes to the coastline. This relation can be represented in a so called $S$-$\phi$ curve. Because of differences along a coastline, for instance near structures, these $S$-$\phi$ curves are not the same along the whole coast. UNIBEST-CL+ uses these $S$-$\phi$ curves to calculate the transport along all of the cross-shore rays, indicated by the user.

To create the user reference line, the line to which the coastline changes are calculated, UNIBEST-CL+ has the ability to work with satellite maps, AutoCAD drawings and other maps. This makes it more easy to give the right input, but also it makes it easier to compare the model results. UNIBEST-CL+ is able to plot the outcome of the calculations directly onto the graphical maps.

More detailed information can be written away in ASCII files or comma separated, to be used in other kind of programs.

Link with other software packages
Besides the ability of UNIBEST-CL+ to import graphical information (Maps etc.), it can import many other data from different kind of engineering software packages. One of the more important options is the data retrieval of the 2DH wave model DELFT3D-WAVE, based on SWAN (DELFT3D-WAVE will be elaborated later). With the use of SWAN wave conditions can be transformed from the deep water wave conditions into shallow water conditions. This is very useful when calculations have to be made in the near shore area, close to coastal structures. The disadvantage is that SWAN depends on the coastal bathymetry, which changes due to longshore transport. So after every calculation with UNIBEST, SWAN needs a new bathymetry to calculate the wave field again. This can be quite time consuming. Therefore an implementation has been made for UNIBEST-CL+ to be able to calculate the effects on the coast in the shadow zone. A total calculation should take a lot less time using this new technique. This study will further elaborate this new development.

Model input:
- Wave climate: significant wave height, wave period, wave direction and percentage of occurrence of each condition
- Tidal regime: current velocities, water levels and percentage of occurrence of each condition coastal profile shape, active zone and active profile height
- Sediment: characteristics of sand or gravel (non-cohesive sediment) parameters related to the selected sediment transport formula
- Parameters for wave propagation
- Coastline shape / position
- Boundary conditions for shoreline model
- Structures: groynes, offshore breakwaters, revetments, sources/ sinks

Model output:
- Wave characteristics along the coastal profile
- Cross-shore distribution of the longshore currents (wave-induced and tidal)
- Cross-shore distribution of the longshore transport
- Relations between longshore transport and coast-orientation
- Gradients in longshore transport along the coastline
- Coastline position, migration and orientation between grid points
- Coastline migration rates between grid points
D.5.3 Diffraction Module

When coastal modeling has to be done for a coast with structures along it, it will be a little more complex. Behind the structure, in the shadow zone, the wave climate changes, it becomes less intense. In the past the program SWAN was used to calculate the representative wave climate behind the structure. It demanded extra computations and with that a lot of extra time.

It is therefore integration is made, into the UNIBEST-CL+ model, of a module that accounts for the diffraction in the shadow zone. The module is based on the Kamphuis (1992) equations.

\[
\begin{align*}
K_d &= 0.71 - 0.0093\theta + 0.000025\theta^2 \quad \text{for} \ 0 \geq \theta \geq -90 \\
K_d &= 0.71 + 0.37 \sin \theta \quad \text{for} \ 40 \geq \theta \geq 0 \\
K_d &= 0.73 + 0.17 \sin \theta \quad \text{for} \ 90 \geq \theta \geq 40
\end{align*}
\]

(D.1) \hspace{1cm} (D.2) \hspace{1cm} (D.3)

\[\begin{array}{ll}
\alpha_s & \text{Incident wave direction [deg]} \\
\delta & \text{Angle of the straight line between the point of interest and the diffraction point [deg]} \\
\theta & \delta - \alpha_s [\deg]
\end{array}\]

Figure D-5: Basics of the Kamphuis formulations