Humplike nourishing of the shoreface

A study on more efficient nourishing of the shoreface

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Preface

The present M.Sc. thesis study forms the final step of my education at Delft University of technology, Faculty of Civil Engineering and Geosciences, section Hydraulic Engineering. The study has been carried out at WL | Delft Hydraulics and was funded by a co-operation framework of Delft Cluster and WINN (WaterINNovation Project) and is falling within the project "More sand with less effort".

This thesis concerns a study to the efficiency of humplike nourishing of the shoreface ("Roelvink suppleties") in comparison with the conventional method of bar nourishing of the shoreface. It is expected that faster onshore transport of sand will occur as a result of hydrodynamics when nourishing the shoreface with smaller humps of sand. Analysing of a number of different scenarios is giving insight in the behaviour of humplike nourishments and will determine the relative efficiency.

I would like to thank my supervising committee, Prof. dr. ir. M.J.F. Stive (Delft University of Technology), Prof. dr. ir. J.A. Roelvink (WL | Delft Hydraulics), dr. ir. M. van Koningsveld (WL | Delft Hydraulics), dr. ir. A.J.H.M. Reniers (Delft University of Technology), ir. D.J.R. Walstra (WL | Delft Hydraulics) and dr. R. Spanhoff (RIKZ/Rijkswaterstaat) for sharing all their knowledge and their support during my thesis study. Furthermore I want to thank WL | Delft Hydraulics for the opportunity and facilities they offered me for completing my study at their institute. Together with my fellow graduate students I had a very pleasant time at WL | Delft Hydraulics. I enjoyed all the lunches and intermezzos during the day a lot and want to thank them for all their interest and helpful input during my thesis.

Finally I want to thank all my friends and housemates thanks to whom I had a wonderful time during the years I spent in Delft, my parents and Paula for their support during my study.

Laurens Koster

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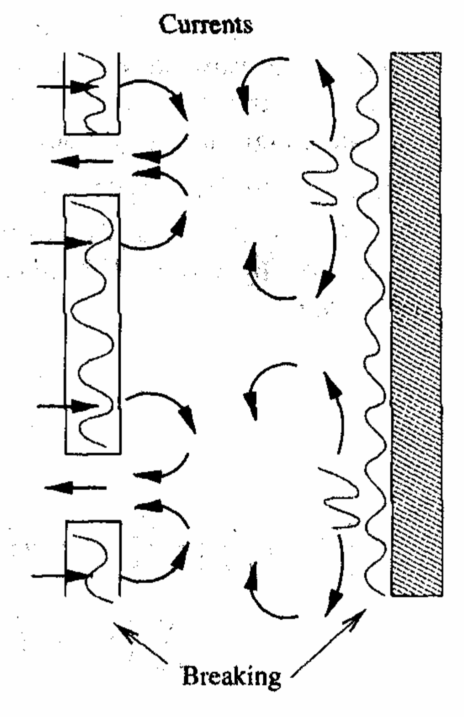
Summary

To preserve the beach and protect the hinterland nourishments are applied to compensate sand loss in the coastal system. Nourishing the shoreface is becoming more popular since more sand can be applied for the same costs compared to beach nourishment. Evaluations of shoreface nourishments executed in the past show that the conventional method of elongated bars results in sediment trapping in the lee of the nourishment. The feeding function of bar nourishing at the shoreface could be improved by applying smart designs of the nourishment. This study analyses a method of humplike nourishing of the shoreface, suggested by Roelvink *et al.* (2005), and finally concludes that:

- Humplike nourishing indeed results in more onshore transport per nourished amount of sand, a clear optimum is found for a hump length of 200 meter with a gap width of 300-500 meter;
- For moderate storm conditions with incident wave angle of 45 degrees with the shoreline, humplike nourishing shows to be 1,75 times more efficient. For more perpendicular waves this value increases to 3 times the efficiency of the original bar nourishing;
- By applying humplike nourishing less sand is used to obtain similar onshore transport and serve the nearshore profile.



Breaking of waves resulting in horizontal circulations
at the bar edges and in the nearshore zone

Nourishment of the shoreface causes waves to break further offshore. Earlier dissipation of energy is compensated by set-up of the water level. Water level variations in alongshore direction form horizontal circulations which lead to an increased onshore sediment transport at the tips of the artificial bar. As a result these tips shift onshore faster. On more humplike nourishments this effect of horizontal circulation cells at the crest of the bar is expected to be used more efficiently (see Figure). With humplike nourishing of the shoreface it is expected that more sand transports onshore with less nourished sand. By not placing the humps too close together, offshore transports due to rip currents will not have great influence on sediment transport.

To investigate the efficiency of humplike nourishments, the simulation suite Delft3D is applied to model the different processes. The model applied is a simplified schematisation for the Dutch coast without the complexity of natural bars. Only the effects of the nourishment itself are analysed. To prevent model errors from having too much influence on the analysis, the reference situation is subtracted in all cases so the autonomous nourishment

behaviour is obtained for comparison. The various scenarios are modelled under exposure to constant wave fields with constant water levels. The hydrodynamic conditions represent a moderate storm and show behaviour of humplike nourishing in a realistic way. All modelling has been executed with a depth averaged area model (2DH).

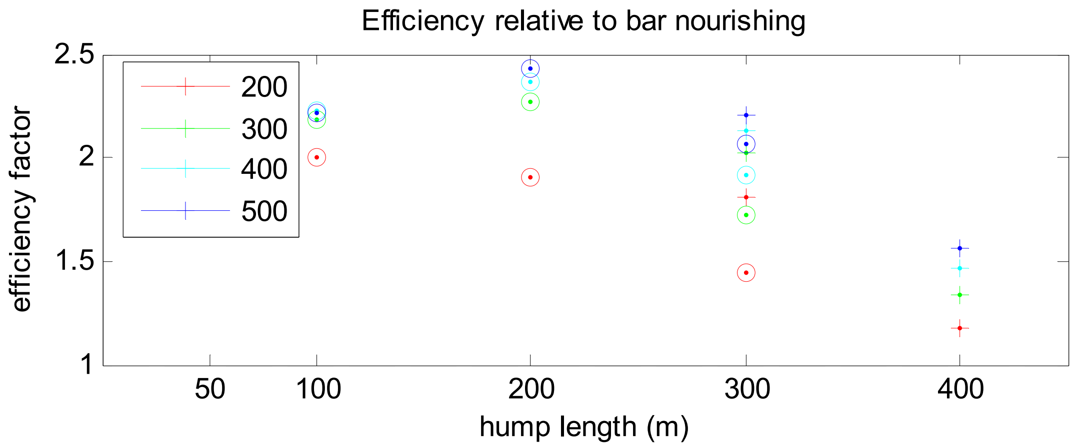
For a number of different humplike scenarios and varying hydrodynamic conditions the initial sedimentation and erosion is analysed. In all cases the net onshore transport over the crest of the humps and bar is used as an efficiency measure. Results indicate that there are advantages in favour of humplike nourishing. The wave induced onshore current at the tips of the bar and the humps leads to complex onshore circulations. Conflicting currents originating from up- and downstream humps and the wave induced longshore current in the breaker zone generate rip currents. As the rip currents flow offshore at deeper water, where sediment concentrations are low, the overall effect is positive. Variation of hydrodynamic conditions shows large differences for these different conditions. In reality behaviour of humps is determined by varying wave heights, incident wave angles and waterdepth. Analysis of these conditions leads to the following conclusions:

- Incident wave angle shows to be of large influence and will determine the success of humplike nourishing. The more perpendicular the approaching wave angle, the better the result of humplike nourishing is. The trapping of sand is mainly determined by the more oblique approaching waves. Variation of wave angle is expected to lead to more gradual behaviour nearshore and accretion onshore in case of the bar nourishing.
- Higher waves and shallow water result in higher water level gradients leading to an increase of sediment transport for the humplike nourishing in comparison with bar nourishing. More contribution of high perpendicular waves within a wave climate leads to more efficiency of the humps.

Variation of hump properties shows large differences in the efficiency of different scenarios. Especially the length of humps has large influence on the morphodynamic behaviour. The longer humps get the more resemblance with the elongated bar is seen and less cross-shore transport per nourished amount of sand is the effect. The gap width shows less impact. A trend is seen in the combination of gap width and hump length. Longer humps show a larger influence of gap width. Evaluation shows results in favour of hump lengths of 300 meter, no matter what the gap width and the number of humps is. In the lee of the humps a chain of sedimentation and erosion spots is caused by wave penetration and gradients in longshore transport. The larger the gaps are the more gradual the differences are. With different wave conditions large differences as a result of rips and contraction of currents are expected to be averaged out over the whole coastline.

Morphodynamic modelling confirms the initial modelling conclusions. Humplike nourishing leads to a faster onshore shift. For the same scenarios as analysed for the initial cases the efficiency is determined for different incident wave angles by means of morphodynamic modelling. Efficiency is now determined by loss of sand volumes in the nourished sections normalised to the nourished amount of sand. It is assumed that all sediment lost in this section is transported onshore. Volume analysis is done after 42 days of morphodynamic modelling under constant conditions. The figure shows how for a constant incident wave angle of 250 degrees and a gap width of 500 meter, a hump length of 200 meter is the optimum and has the largest gain onshore. 2,9 % onshore gain for the bar versus 6,9 % for the humps leads to an efficiency which is 2,5 times larger. More alongshore

approaching waves show a clear decrease in efficiency for the humplike nourishing in contrast with the efficiency for the bar which is approximately constant.



Efficiency of the various nourishment scenarios divided by the efficiency of the bar nourishing scenario, different colours represent the different gap widths of the scenarios

The nearshore behaviour of the different scenarios is hard to get grip on. Large disturbances are shown here in the form of sedimentation and erosion spots. By averaging the lee zone effect of the nourishments over a section the influence on the nearshore zone is analysed. It turns out that humplike nourishing reduces the effect of sediment trapping

For further study it is recommended to apply an existing bottom schematisation and boundary conditions. In this way transport processes can be described more precise and the efficiency on the longer term can be determined together with a more detailed analysis on the onshore processes, sedimentation and erosion. Together with this follow-up study, execution of a pilot project is recommended in combination with high resolution monitoring of its behaviour.

Contents

Appendices

1 Introduction

1.1 Coastline conservation

Coastline management to preserve the beach and protect the hinterland is an important issue in the coastal zone. Especially in this zone populations are high and the investments are of large value. On the other hand the coastal zone is a vulnerable area due to the dynamics of wind, waves and water level. These two aspects contribute to the fact that a clear policy for the preservation of the coastline is necessary. Structural erosion of the coast is therefore unacceptable.

In the Netherlands a large part of the hinterland is protected against the sea by a combination of beaches and dunes. This system originally is a dynamic system, moving back and forth. Because of the pressure of the population, moving landward of the shoreline is not accepted and erosion of the coastline has to be prevented. In direct relation with this a policy has been formulated for maintaining the shoreline of 1990, see Appendix A.

Shoreline preservation is mainly executed by nourishing the beach and the shoreface with sand. Nourishing the coast with sand is in fact adding an extra sacrificial layer to the profile. Roughly two types of nourishments are being used to compensate the loss of sand in the coastal system: beach and shoreface nourishments. Beach nourishments are directly placed on the upper part of the beach profile. A more recent development is nourishing the shoreface. In the latter case natural processes are expected to move the sand up the beach profile. Shoreface nourishments apply roughly twice the amount of sand as beach nourishments for the same price. Furthermore negative effects on beach use are negligible.

As a result shoreface nourishments are being used more and more. Evaluations show that the efficiency of these nourishments could be approved (Van Duin *et al.*, 2004). Roelvink *et al.* (2005) suggests more hump-like nourishments to stimulate the onshore mechanisms. This report deals with these humplike nourishments of the shoreface. This alternative method is making much more use of the wave-driven horizontal circulations leading to onshore transport and will be potentially more effective.

1.2 Project context

The work reported in this thesis was financed by the Delft Cluster 2 project “North Sea and Coast” (DC 05.02). Part of the work of Workpackage 2 of that project is co-financed by the WINN (WaterINNovation) framework, as part of the project “More sand, less effort”. Together with partners from Delft University of Technology, Unesco IHE and Rijkswaterstaat RIKZ, WL|Delft Hydraulics develops a number of innovative technical-morphological adaptation scenarios to deal with the effects of sea-level rise. The work has focused on three scenarios mainly, viz.:

- "Broad beach, Better surfing", investigating a more efficient way of shoreface nourishment in a context of coastline management.
- "Plenty of Sand, Naturally safe", investigating a more natural approach to dune strengthening in a context of protection from flooding
- "Sand for the Wadden sea, Preservation of the flats", investigating an innovative approach to increase the robustness of tidal inlets in a context of dealing with the adverse effects of sea-level rise.

The work reported in this thesis is a contribution to the first item on the above list: "Broad beach, Better surfing". Main objective is to analyse the efficiency of an innovative way of nourishing, with respect to previously used more traditional methods.

1.3 Outline of report

This report will give some understanding on the efficiency of shoreface nourishments. In particularly humplike nourishments, a chain of smaller nourished humps, are being studied. The report is subdivided into 7 chapters, outlined as follows (Figure 1-1):

Chapter 2	Practical and theoretical introduction to the subject and formulation of hypothesis and objectives;
Chapter 3	Modelling approach and schematisations of the applied model including the parameter settings;
Chapter 4	Hydrodynamic analysis of bar nourishing and humplike nourishing of the shoreface with inclusion of varying hydrodynamic conditions;
Chapter 5	Hydrodynamic analysis with variations in hump length, gap width and number of humps;
Chapter 6	Morphodynamic analysis of humplike nourishing and determination of the optimum humplike design;
Chapter 7	Conclusions and recommendations.

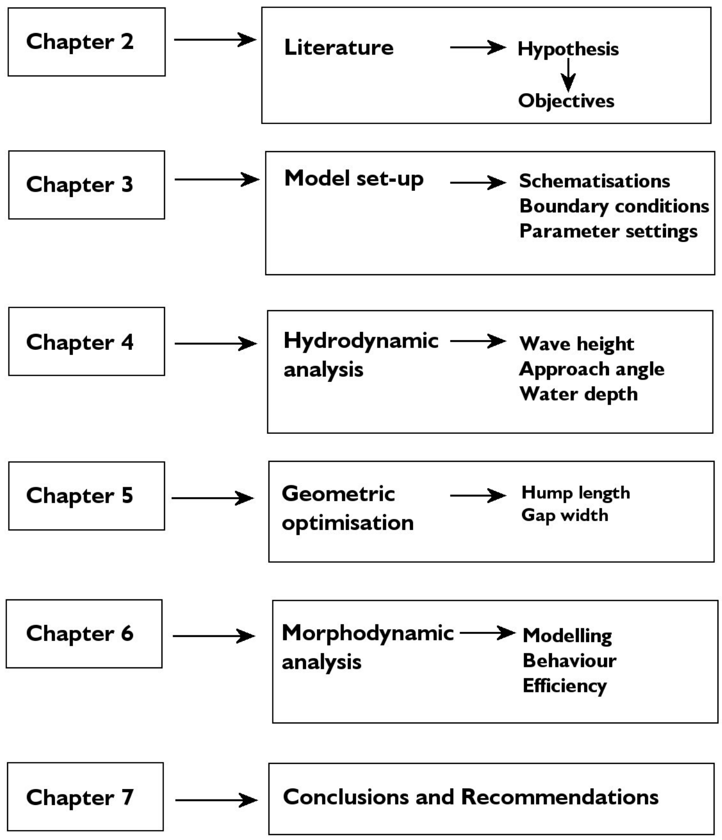


Figure 1-1 Outline and contents of the report

2 Nourishing the shoreface

This chapter evaluates currently used shoreface nourishing methods. Based on these insights an alternative design is suggested. In paragraph 2.1 and 2.2 shoreface nourishments will be described in short and some evaluations of recent nourishments will be discussed. Hereafter the hypothesis for the thesis will be formulated, founded and in relation with the hypothesis the objectives for further research will be formulated.

2.1 Lessons learnt from literature

Since 1970, research has been done on shoreface nourishments and the offshore berm was introduced in South Africa by Zwamborn *et al.* (Westlake, 1995). Shoreface nourishment can be seen as a submerged structure such as a soft reef or a submerged breakwater. Reef berms can be subdivided into (Van Rijn, 2004):

- Stable breaker berms, (deep water) the reef or berm only has a hydrodynamic effect by functioning as a wave filter dissipating the energy of the larger breaking waves and creating a sheltered area in the lee of the reef. Most of the original volume of a stable reef is retained and the reef may remain at the placement site in deeper water (water depth > 10-15 m) for years;
- Active feeder berm, (shallow water) the berm is placed at a nearshore site in relatively shallow water (water depth < 8 m), where it will show significant dispersal of sediment during the initial period. It is supposed to act as a feeder berm for the adjacent beaches resulting in widening of the beaches. The effectiveness increases with decreasing distance to the shoreline. Regular maintenance of the feeder berm is required to ensure a continuous flow of sediment to the beaches and for the berm to be fully effective.

The presence of submerged berms will have an effect on the hydrodynamic and morphodynamic processes in the surf zone. Processes relevant for the success of shoreface nourishments are the following:

The submerged berm results in waves breaking more offshore from the shoreline than in the case without the berm. In the normal situation a longshore current is forced due to dissipation of energy in the surf zone causing a variation of radiation stresses (Longuet-Higgins, 1964). Reduction of the longshore current in the lee zone of the berm will cause accretion of sand upstream of the current and erosion downstream of the currents (Figure 2-1a).

Due to the decreasing waterdepth above the sand mounds in the nearshore zone breaking of waves will occur. The breaking of waves has an effect on the water level behind the berm. Early dissipation of energy leads to a set-up and gradients of water level direct behind the berm and will lead to horizontal circulations in the lee zone of the submerged berm. Especially on the tips of the berm these circulating currents will occur (Figure 2-1b).

The difference in breaking location, on the bar-crest or in the surf zone, leads to different set-up levels. This leads, besides of the circulation around the edges of the berm, to a circulation current in the surf zone. These currents are the driving forces for rip currents (Dalrymple, 1978).

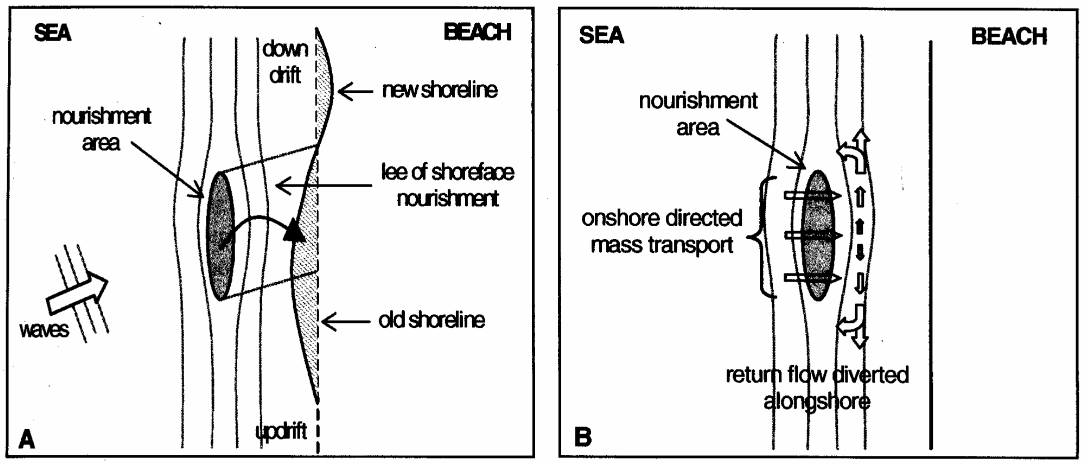


Figure 2-1 Effects as a consequence of shoreface nourishment (van Rijn *et al.*, 2004)

Cross-shore transport in the surf zone causes on and offshore transport of sand. Breaking waves bring sediment in suspension and shoaling of waves in the surf-zone results in wave asymmetry, onshore currents and net onshore transport. The deeper the water the less sediment is brought into suspension by waves. The presence of a berm has a positive effect on the sediment transport.

Water particles in a wave-crest move faster than the particles in the trough of the wave, this phenomenon results in a pressure increase (Stokes drift) as the wave reaches the coast. This pressure is compensated by a current close to the bottom. After breaking of the waves the propagating wave in the surf zone will be smaller, resulting in a smaller Stokes drift and as a consequence in a smaller undertow than in the original situation.

2.2 Lessons learnt from practice

To protect the shoreline from erosion several shoreface nourishment projects have been executed in the recent years. A summary of nourishments since 1997 was presented in Spanhoff *et al.* (2003). In this paper it is concluded that most nourishments behave similarly and are quite successful. Most of the nourishments were executed shoreward of the outer bar. The Dutch North Sea coast consists mainly of a complex natural bar system, complicating the morphology of the surf zone. The alongshore bars are always submerged and have great impact. After a shoreface is nourished, the profile has to find a new equilibrium in which the natural bar system changes together with the new nourished bar. The nourishments were all executed in the form of a feeder berm, to supply sand to the surf zone and to cause seaward growth of the coast line. The latter effect is not only obtained by the nourished sand but is an effect of trapping of sand as well. This will be discussed later in this study.

Three evaluations of shoreface nourishments are considered in more detail (Spanhoff *et al.*, 2003):

- Egmond aan Zee, shoreface nourishment along the Dutch coast. Data analyses and Modelling (van Duin *et al.*, 2004) and (Van Duin and Wiersma, 2002);
- Terschelling, shoreface nourishment at a barrier island. Data analysis. (Spanhoff *et al.*, 1997) and (Grunnet *et al.*, 2004);
- Delfland, shoreface nourishment along the Dutch coast (Rijkswaterstaat/RIKZ 2002).

Egmond aan Zee

In 1999 a shoreface nourishment was applied at the outer bar of the Egmond coast over a length of 2250 m with a characteristic volume of 400 m^3/m at a depth of -7,5 m. The Egmond coastal profile is a three bar system of which two bars are breaker bars. The bathymetry after the shoreface nourishment is shown in Figure 2-2. In the period May-1999 to June-2001 6 bathymetry measurements were carried out.

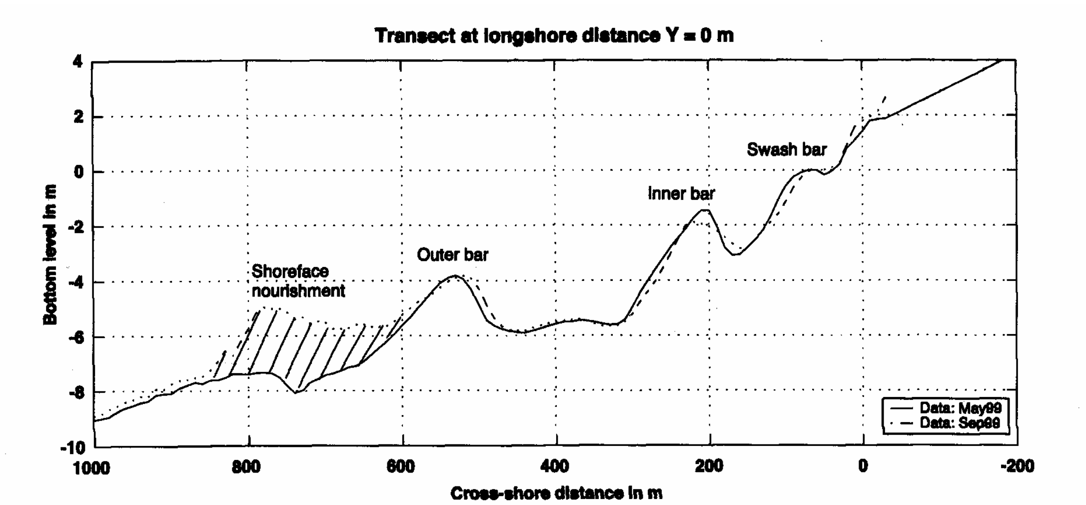
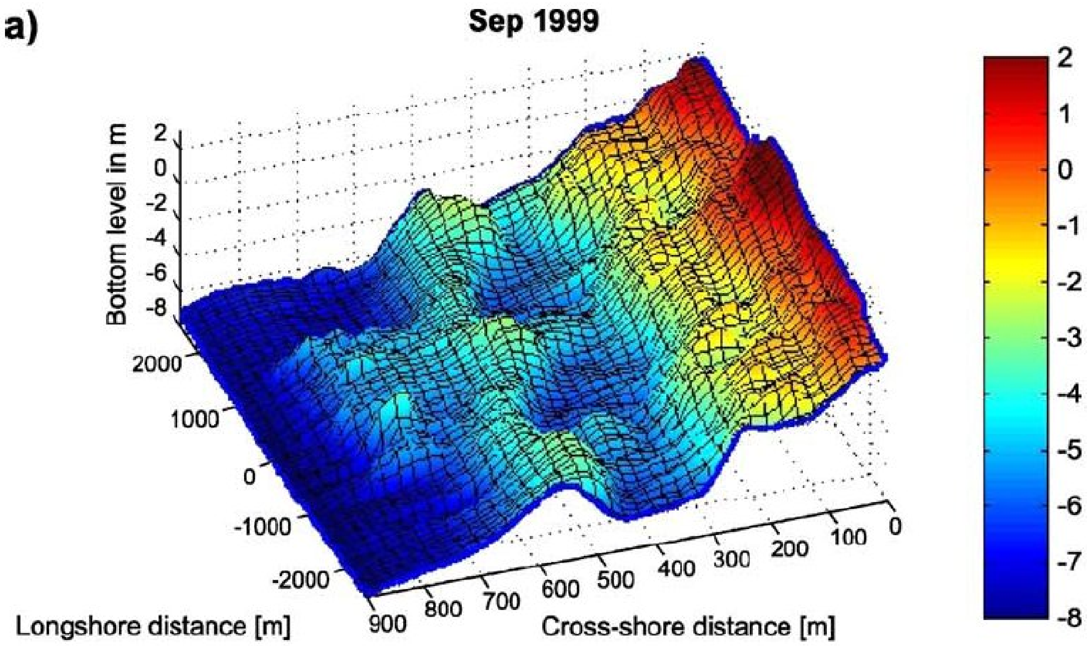
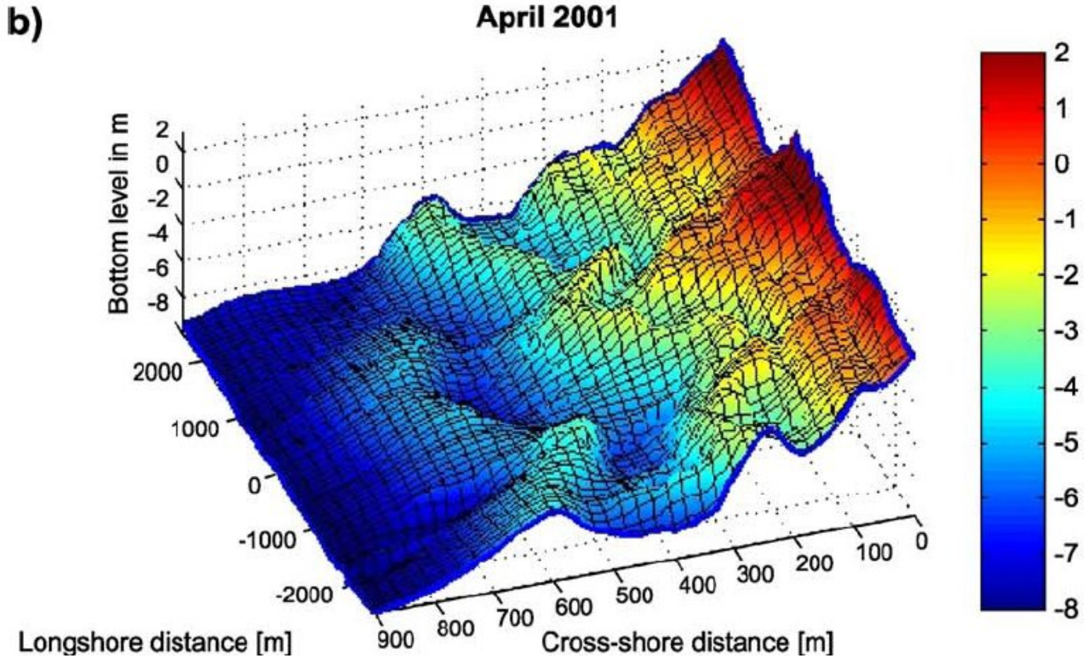


Figure 2-2 Egmond cross-shore profile including shoreface nourishment (van Duin *et al.*, 2004)

Conclusions from the evaluation of the data analysis are the following. In Figure 2-3 3D images of the bathymetry are shown at different times.

- The edges of the nourishment seem to migrate shoreward faster than the middle section of the nourishment;
- Strong effects after the second year of the nourishment. The nourishment flattens and diffuses;
- Shifting of outer bar to inner bar location. Formation of trough between the outer bar and the nourishment;
- Gain of sediment in the lee zone of the nourishment as a cause of trapping of sediment;
- Extra beach nourishments for compensation of initial losses in the lee of the nourishment.


a)
Sep 1999
Bottom level in m
Longshore distance [m]
Cross-shore distance [m]


b)
April 2001
Bottom level in m
Longshore distance [m]
Cross-shore distance [m]

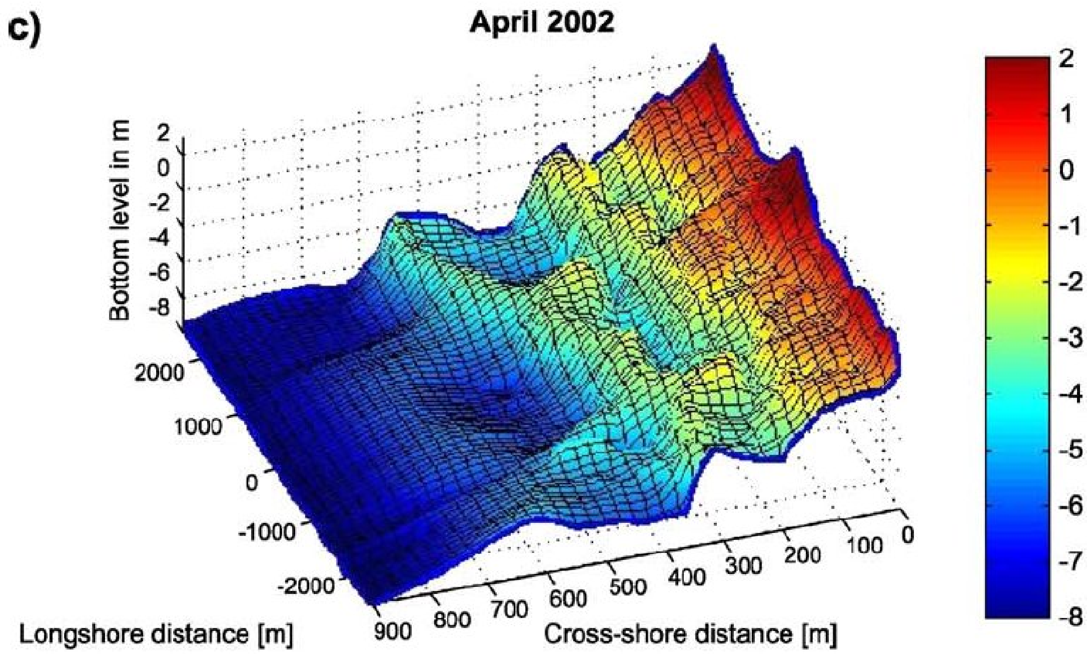


Figure 2-3 Bathymetry evolution of Egmond nourishment (van Duin *et al.*, 2004)

Conclusions from the Delft 3D modelling in 2DH mode, being depth averaged:

- Wave energy is dissipated at nourishment instead of outer bar, causing a calmer wave climate onshore;
- Decreased flow velocities shoreward of the nourishment and increased flow velocity seaward;
- Good comparison in erosion/sedimentation patterns, the cross-shore profiles do not show much resemblance with the measured profiles.

Terschelling

In 1993 a shoreface nourishment was implemented in the trough between the outer bar and middle bar of the Terschelling coast. Over a length of 4400 m with a characteristic volume of 450-500 m^3/m at a depth of -4,5 to -7 m. Terschelling is one of the northern barrier islands of the Dutch coast. The Terschelling coastal profile is a three bar system. Large difference with the Egmond nourishment is the allocation of the nourishment in between the bars and the heavier wave climate the island is exposed to compared to the straight western coast of the Netherlands. Alongshore transport along the northern coast of the Netherlands is in the order of 2-4 times larger than along the straight Holland coast (Spanhoff *et al.*, 2003).

Some results from the data analysis are the following:

- Fast redistribution of sand in the disturbed area, strong erosion of the nourished sand in alongshore and cross-shore direction in the first 6 months;
- Growth of middle bar by gain of sediment from updrift sections, sediment is trapped in the lee zone of the nourishment and will accrete there;
- Strong shift of the nourishment alongshore (400 m/yr);
- On the longer term, 4 years, the shoreward section of the nourishment showed large accretion. The seaward section of the nourishment showed minor accretion.

Delfland

Delfland is located on the southern part of the straight Holland coast. In 1997 a shoreface nourishment was implemented in combination with a beach nourishment. Over a length of 1,7 kilometres the shoreface was nourished at a depth of NAP -5 to -7 meter with an amount of about 500 m^3/m. The Delfland nearshore profile consists of a minor bar-system and a relatively small alongshore drift (Rijkswaterstaat/RIKZ 2002).

After evaluating the shoreface nourishment after almost 5 years a number of conclusions were made.

- Loss of sand at the nourishment section, the nourished sand eroded to nearshore sections (-200.000m^3);
- Increase of sand in the beach section east to the nourishment (+300.000 m^3);
- Accretion of northern and southern section of the nourishment (+100.000-150.000 m^3);
- About 70 % of the originally nourished sand is still present in the profile after 4 years of the nourishment;

Conclusions and discussion

Overall it can be concluded that the final sand budget in the nourishment zone increases after the implementation of a nourishment in the form of a feeder berm. The so called feeder berm flattens out and the sand is transported to onshore sections. In general seaward transport does occur but is so small that it can be neglected.

Not only sand is supplied from the nourished sand, sand is coming from updrift sections as well. As a result of wave dissipation at the newly formed bar a weaker wave climate is caused at the lee of the bar and sand is trapped so it will accumulate. Finally an amount in the order of 50-70 % of the initially nourished sand is still in the nourished nearshore section after 3-5 years. The lee zone beach section benefits on a longer time scale of the shoreface nourishment and therefore supplementary beach nourishments are executed to widen the beach. The feeder berm needs additional nourishments as well, as the lifetime of a shoreface nourishment is about 2-10 years the efficiency will decrease (van Rijn *et al.*, 2004).

The evaluations show good comparison with the in paragraph 2.2 discussed hydrodynamic and morphodynamic phenomena, though it is hard to forecast how the morphologic system reacts to the differences in the nearshore profile. Bar systems are dynamic systems and implementation of disturbances in these systems will lead to unexpected results. The wave climate and bathymetry are different at every location and have a large influence on the response of the nearshore profile. Eventually the profile will return to a profile similar to that of the original situation.

Less attention was paid to the migration of the edges of the nourished bars to the coast. Especially in the case of Delfland and Egmond a clear migration and accretion has been seen of the northern and southern sections of the nourished bar. This phenomenon is probably the result of horizontal circulations around the edges and will be the essence of this thesis and following paragraphs will focus on this.

2.3 Theoretical foundation introducing the hypothesis

As mentioned above, in the observations clear migration of the edges of the nourished bar shoreward could be seen. Apparently different processes at the edges of the bars occur than in the other sections of the shoreward zone of the shoreface nourishment. Horizontal circulations in the nearshore zone cause migration shoreward of the bars and accretion of the edges at the leeside. This paragraph will deal with different aspects of horizontal circulation in the nearshore zone; finally a hypothesis will be formulated and founded.

2.3.1 Horizontal circulations in the nearshore zone

In general rip currents are the offshore currents in the nearshore zone causing bathymetry variations and have an erosive character. Especially in coastal systems with bars in the nearshore zone rip currents are common (Wright and Short, 1984). In general rip currents are activated by alongshore variations of wave fields caused by instabilities or non-uniformities in the surf zone (Dalrymple *et al.*, 1978). Rip currents can be classified into two mechanisms creating the alongshore variation, needed for the generating of rip currents.

- Wave interactions, edge waves interacting with incoming short waves, waves interacting with currents and interaction between wave-trains;
- Structural interaction, rips as a result of variations in bathymetry and structures.

Wave breaking leads to an energy dissipation and as a consequence in a variation of the radiation-stresses. This latter variation will result into a set-up. Waves breaking at different locations due to interactions in the breaker zone will lead to differences in set-up which is the actual cause of the rip current due to structures like nourishments.

As seen in Figure 2-4a (Haas *et al.*, 1998), in a bar system the waves will first break at the crest of the bar and cause a set-up there. The waves propagating in the channel will break more shoreward resulting in two main horizontal circulations. The first from the bar crest direct into the channel between the bars, the second in the leeside of the bar in the opposite direction. The described circulation cells are clearly seen in an experiment of Haas (Haas *et al.*, 2002), see Figure 2-4b. The experiment shows a concentrated outflow through the channel between the bars, and a clear flow of the bar-edges alongshore. This current can reach far offshore where it spreads out into so called rip heads.

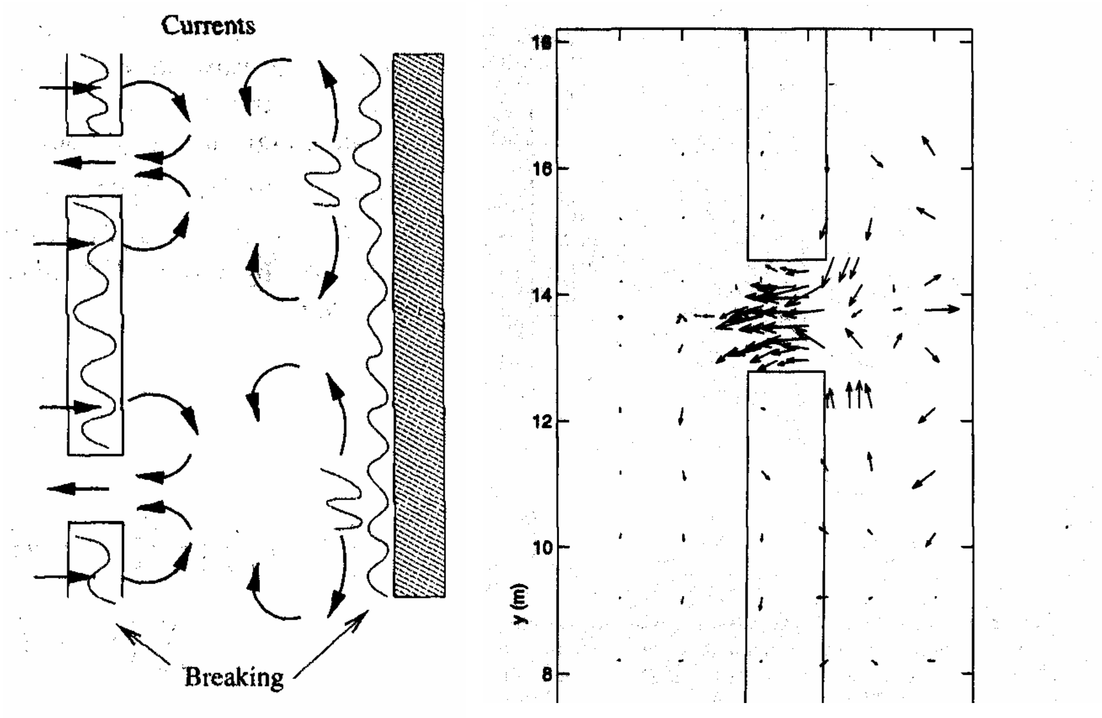


Figure 2-4 a) Horizontal circulation cells. b) Velocity vectors as result of rip current

2.3.2 Three-dimensional flow velocity and sediment transport

An interesting aspect of rip currents is the three-dimensional character of it. In literature most models used for wave induced nearshore circulation are based on depth-integrated, time-averaged laws of mass and momentum (Chen *et al.*, 1999). The vertical profile of the current is found to be varying from uniform over the depth near to the shore and in the channel to depth varying further offshore. This depth varying is both in magnitude as in direction. (Haas *et al.*, 2002) and (Drønen *et al.*, 2002)

Two experiments were executed to investigate the depth variability of rip current velocity. Both experiments will be dealt with in short.

Drønen *et al.*, 2002

Drønen *et al.* (2002) performed an experiment in a 4 m wide and 30 m long wave tank. In the wave tank a model of a bar was set-up to cause a rip current. The bathymetry was kept constant so only the velocity profiles were measured. Due to the sidewalls the rip current was not able to develop in alongshore direction. See Figure 2-5 for set-up of experiment. During the experiment tests were performed with different wave height, wave period and waterlevel.

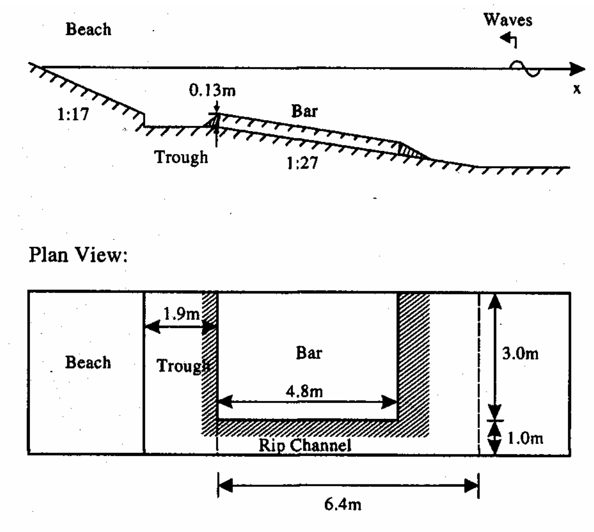


Figure 2-5 Sketch set up of experiment (Drønen *et al.*, 2002)

Overall conclusions from the experiment of Drønen in relation to the velocity distribution are:

- A mean horizontal velocity field was obtained, comparable with the one in Figure 2-4;
- Fluctuations of the water level close to the transition between the bar crest and the rip channel;
- On the bar crest and around the bar, there where it meets the rip channel, the orientation of the flow seems to vary over the depth.
- The current seems to be stronger near the bottom at the start of the channel. More offshore the current losses the bottom and even changes direction onshore. Some results are presented in Figure 2-6.

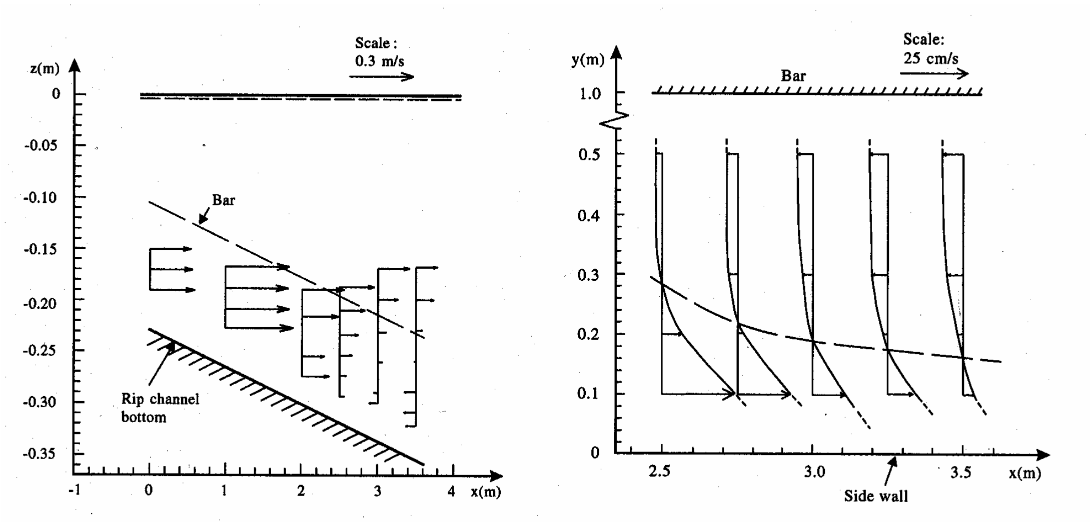


Figure 2-6 Varying velocity over cross-shore profile in rip channel, in depth and alongshore (Drønen *et al.*, 2002)

Not clear from the Drønen experiment is the effect of the sidewalls forming standing edge waves and giving perturbations of the actual situation, though it is suggested that standing edge waves can exist in a more complex bar-system as well. The effect of the edge waves would be an order smaller than the phenomena resulting in the observed horizontal circulation cells.

Haas *et al.*, 2002
The experiment Haas (2002) performed was similar to that of Drønen. Largest difference is that the wave basin was more wide and one whole bar and two half bars were modeled. The same set-up was used before (Haller *et al.*, 1997) to obtain information about horizontal spacing of rip currents as a result of wave heights and water levels. In the Haas experiment, for a number of locations and different wave impact and water level the velocity is measured at three different depths. The velocity at the bottom primarily affects the sediment transport, so the depth variation of the velocity is expected to be of large importance. The experiment's conclusion is that the velocity distribution in the channel is mainly uniform, more offshore the bottom velocity varies strongly over the depth. Velocities around the edges of the bar were not measured so no conclusions could be drawn on vertical variation from this experiment.

Conclusion
Overall conclusion from the experiment is that the effect of the circulation cell around the edges is stronger near the bottom and in alongshore direction. As the rip current is building up and meeting the channel, the vertical velocity distribution changes and the velocity is getting stronger in the upper part of the water mass. This could be a possible reason for the sediments accreting at the bottom near the edges of the bar. An important finding is the three-dimensional variability of the velocities around the edges of the bar and in the offshore rip channel.

2.3.3 Horizontal circulation by vortex generation

Chen *et al.*, 1999
The experimental set-up introduced above (Haller *et al.*, 1997) inspired a numerical simulation to investigate the interaction between surface waves, rip currents and bathymetry (Chen *et al.*, 1999) and its dependency on vortex generation. The model was created slightly asymmetric to obtain more real results. Figure 2-7 shows the first results of the modelling. There is a clear difference in wave breaking location and therefore especially on the edges large water level variations arise, causing vortices.

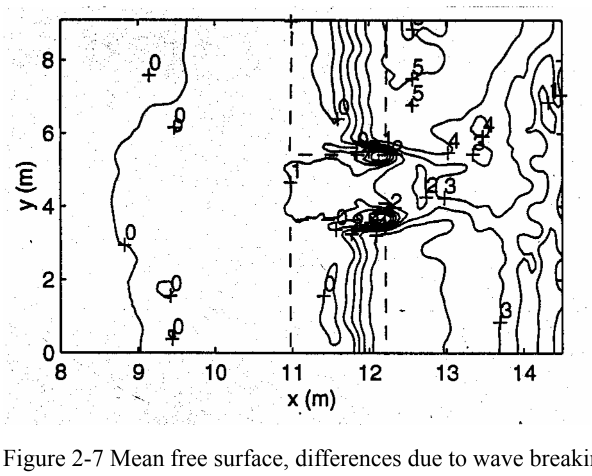


Figure 2-7 Mean free surface, differences due to wave breaking (Chen *et al.*, 1999)

A sequence of different computations in time is presented in his paper to describe the temporal and spatial variation of the rip current system. It was concluded that the rip current meanders its way out of the rip channel and that velocity is oscillating with constant period.

To investigate the dependency on perturbations in the bathymetry on the crest of the bar and the surf zone, vortex generation was modelled on a non-disturbed bar profile. It turned out that bathymetry perturbations have large influence on the spatial and temporal variation. The long-term-averaged forcing of the rip current is similar in the two situations; there is a delay in getting instable of the rip current as the bathymetry is smoother.

Another process discussed by Chen *et al.*, (1999) is the refraction/diffraction effect of rip currents on waves. Especially in the case without the perturbations the influence of wave diffraction is clearly present due to the more organized vortices.

2.3.4 Influence of wave height, directional spreading and water depth

Rip currents appear to be stronger during low tide (Aagaard *et al.*, 1997). Rip activity depends on the degree of wave energy dissipated by breaking waves. The ratio between breaking waves and water depth under the breaking wave has a constant value so low tide results in larger energy dissipation.

Drønen *et al.* (2002) concludes the following from his experiment, described above, on wave variation:

- Rip current velocity moves offshore as the wave height increases and water level decreases;
- The location of breaking of waves at the bar will influence the flow of water into the surf zone. Waves breaking seaward of the bar tend to direct over the bar in lateral direction into the channel. Waves breaking close to the bar crest will propagate into shoreward direction;
- Wave breaking is not influenced by wavelength, a difference in peak period did not influence the intensity of the rip current;
- The velocity field is developing over a larger horizontal surface by irregular waves than by regular waves. This is a result of the waves breaking at different locations.

The coast can be classified as a high and a low energy coast, being dependent on the breaking wave heights. Comparing different energy coasts (Brander *et al.*, 2000) it can be concluded that there is a direct relationship between the morphology of the two systems and the hydrodynamics. Roughly, a two times heavier wave climate results in rip currents reaching two times further and velocities being two times larger as well.

Individual wave groups vary in wave energy, this results in a strong spatial modulation of vortices in the surf zone (Reniers *et al.*, 2004). Vortex dynamics in the surf zone cause horizontal flow and therefore sediment transport. One of the conclusions in Reniers *et al.* (2004) is that there is a relationship between the alongshore length-scale of the wave groups and the scaling of channels and shoals. Increase of directional spreading will decrease the time-averaged magnitude of circulations in the nearshore zone.

2.4 Hypothesis and objectives for research

In the previous paragraphs processes active in the nearshore zone are discussed. Evaluations of shoreface nourishments executed in the past show that the conventional method of elongated bars is not always as efficient as it was thought to be. The trapping of sand causes an important contribution to the shoreline. This is the result of the calmer wave climate. The tips of the nourished bars are shifting onshore faster as a result of variations in water level above the crest of the bar. These water level variations form horizontal circulations leading to an increased onshore sediment transport.

Hypothesis
Humplike nourishments cause more onshore transport than bars because the positive effect of horizontal circulation cells at the crest of the bar is better used.

By executing shoreface nourishments in the form of humps, more sand is transported onshore as a result of less implemented sand and thus smaller alongshore disturbances of the bathymetry. By not placing the humps too close together, rip currents offshore will not have great influence on sediment transport. The placing of humps on the shoreface instead of elongated sandbars will overall result in a faster shift of the nourishment to the shoreline and thus contribute better to the coastline than the conventional method, Figure 2-8.

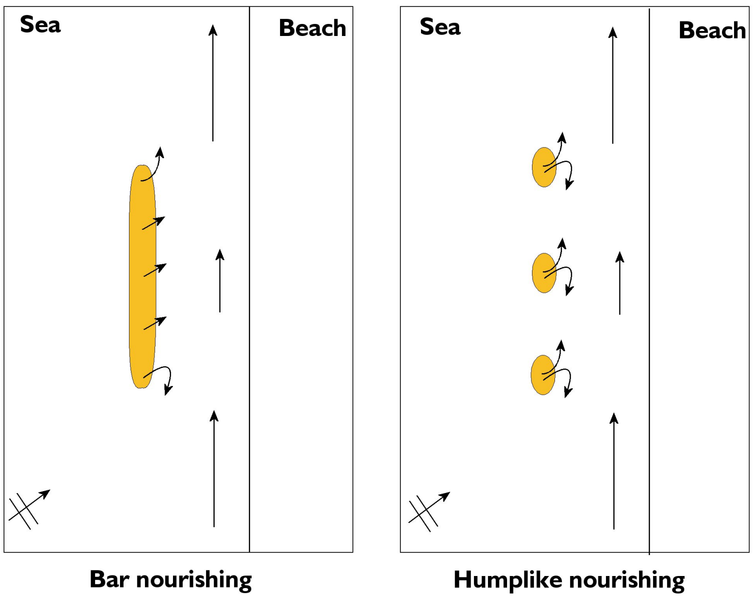


Figure 2-8 Circulations at bar nourishing and around humps founding the hypothesis

2.4.1 Objectives of the study and general approach

General objective of this thesis will be to test the above mentioned hypothesis. With the help of a numerical model simulating the hydrodynamic and morphodynamic processes in the nearshore zone this study will give insight in the efficiency of humplike nourishments. If the hypothesis is correct this study can be used as a guideline for a new nourishing method and how to implement nourishments on the shoreface in a most efficient way. Not every aspect responsible for the behaviour of the humplike nourishments will be dealt with. Only a first qualitative analysis is presented showing whether it is of interest to further investigate the possibilities.

The report follows an approach, which deals with all the wave related aspects of hump nourishing. For this study only the effect of waves on nourishments were analysed. Waves are expected to be the main cause for the way shoreface nourishments behave and therefore tide is beyond the scope of this report. In relation with the posed hypothesis a total of 3 objectives will be worked out:

Objective number 1: Getting insight into the hydrodynamic behaviour around humplike nourishments and bar nourishments

Main objective for this part is to get insight into different conditions like waves and water depth on the hydrodynamics around shoreface nourishments. The analysing of the varying of conditions will be executed on a number of fixed bathymetries. For this part a transport parameter is introduced which enables to compare different situations and so to determine the effect of varying conditions on the onshore moving of humps.

Objective number 2: Optimisation of the humplike shoreface nourishment by varying geometric properties

This part is more or less the design part of the study. Different bathymetries will be analysed. By varying the length of individual humps and the gaps between mutual humps an analysis will be done on the possibility of influencing the efficiency of the new method. Important questions to be answered are, what is the ideal length of the humps in longshore direction, what is the best gap width to apply and what is the relation between those.

Objective number 3: Determine the morphodynamic behaviour of humplike nourishments

The hydrodynamics were only analysed for the initial situation. As the conclusions of the literature mentioned the initial response of the nourishment is largest. The situation is most unnatural during this phase and reshaping will be a result.

3 Modelling humplike nourishments

3.1 Modelling approach

To investigate the efficiency of humplike nourishing of the shoreface in comparison with bar nourishing a plane longshore uniform model bathymetry is used. The model is a simplified schematisation representative for the Dutch coast without the complexity of natural bars. In this way the autonomous effect of the nourishments only can be analysed. To minimise the effect of model errors, predictions will be compared with a reference situation without nourishments so the focus will lie on relative effects only. Paragraph 3.2 will deal with the model schematisations in more detail. Later parts of the study will work with a number of scenarios based on the presented model schematisations.

For boundary conditions only exposure to a constant wave field with constant water level is modelled. Wave conditions are representative for a moderate storm and will show the behaviour of humplike nourishments. Wave conditions and water level will be varied to see the impact of various properties.

All modelling was executed with the numerical model Delft3D. A short description of the Delft3D model is given in Appendix B-1, for a more elaborate description reference is made to the Delft3D manual. All modelling has been executed with a 2DH, depth averaged area model. This will be dealt with more elaborate later in this chapter.

The approach described results in the following steps made during the course of this study:

- Application of a profile model of the reference model for determination of the transport parameter settings. A 2DV model with the Egmond (Walstra *et al.*, 2004) parameters was used for calibration;
- Application of the calibrated model settings for hydrodynamic simulations on bar nourishing and a single humplike nourishing scenario. This part will deal with hydrodynamic variations as well;
- Modelling of various humplike scenarios to analyse the properties and influence of gap width, hump length and number of humps;
- Morphodynamic modelling of humplike scenarios and comparison of the predictions being made by the model. More detail on the principles of morphodynamic modelling will be discussed in Chapter 6.

3.2 Model schematisations

Bathymetry

The simulations performed during this study are executed on a plane bottom profile. Former studies, which were mainly evaluations and predictions of executed nourishment projects, used the actual bottom profiles to analyse the effect of the implementation on the bathymetry and simulate sedimentation and erosion. Objective of this study is to increase our understanding of the positive and negative effects of various nourishing scenarios and the processes being active. Gained knowledge can be used for implementation of a nourishment scenario with a positive result in a realistic situation.

The simulation model being applied consists of a coastal area of 2500 meters in cross-shore direction by 6500 meters alongshore. During the study different bathymetries are applied for nourished humps and bars. The orientation of the model area is exactly East-West, meaning that the seaward boundary is the Western boundary and the landward boundary is the Eastern one. The x = 0 line corresponds with the seaward boundary of the model. The landward boundary of the model varies as the water level varies in different simulations and due to the tide. The water level reaches up till x = 2300, so the extra 200 meter of beach leaves enough profile height to let waves run up during high water. Y = 0 is the most southern boundary of the model. The model has a latitude of 52^0 which is representative for the Dutch coast.

In Figure 3-1 a nourishment scenario is illustrated showing 3 nourished humps of 100 meter and a mutual distance of 200 meter. The crests of the nourishments have a flat surface with a width of 50 meter. The slopes of the humps are assumed to be Gaussian after nourishing. The humps are implemented in the model by adding an amount of sand on the initial bathymetry following the next equation.

$$z(x,y) = d_{hump} \exp \frac{(x - x_{hump})^2 + (y - y_{hump})^2}{2\sigma^2} \qquad \text{3-1}$$

d_{hump}	=	depth at centre of hump (m)
x_{hump}, y_{hump}	=	coordinates at centre of hump (m)
σ	=	parameter for maximum slope (m)

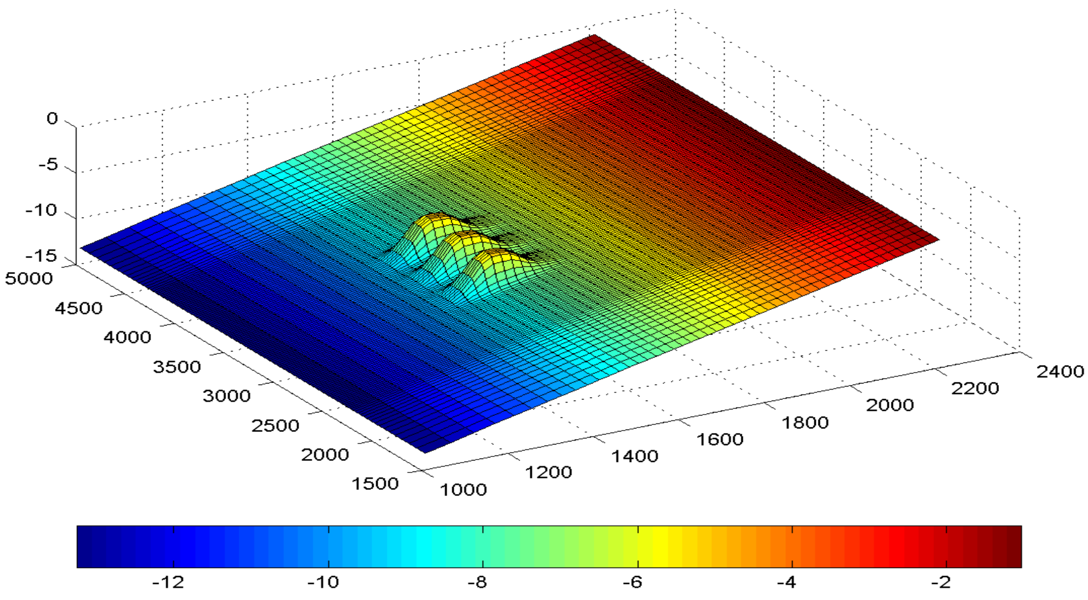


Figure 3-1 Nourishment designs implemented on the model bottom, 3 humps with dimensions of 50 by 100 with a gap width of 200 meter

The standard deviation being applied in the formula is a measure for the slopes, the seaward slope has a maximum value of 1:15. For the first sections of the report four bathymetry designs are used, in later sections the dimensions and locations of the humps and the number of humps will be varied.

In Figure 3-2 a cross-section of the nourished humps is shown together with its properties. The humps centre lies on a distance of 600 meter from the waterline and has a minimum depth of 3 meters. The hump has a height of 3 meter as well, this makes that the total amount of sand needed for the nourishing is approximately 450 m^3/m.

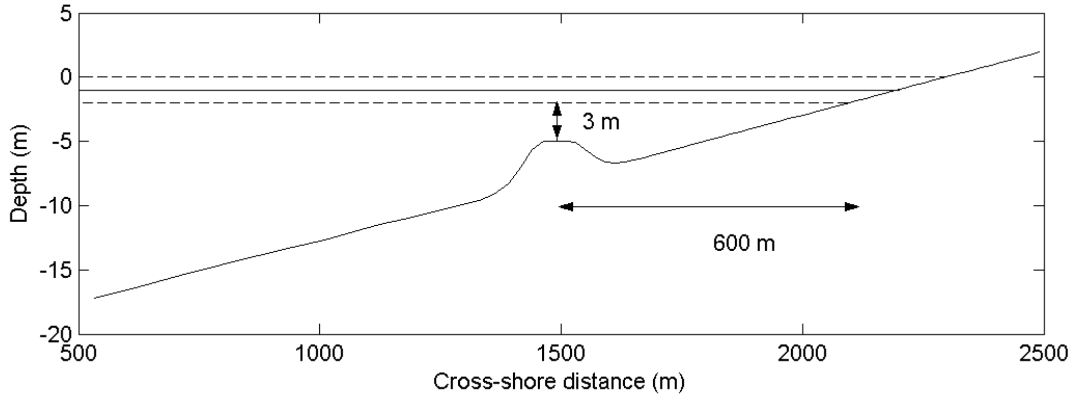
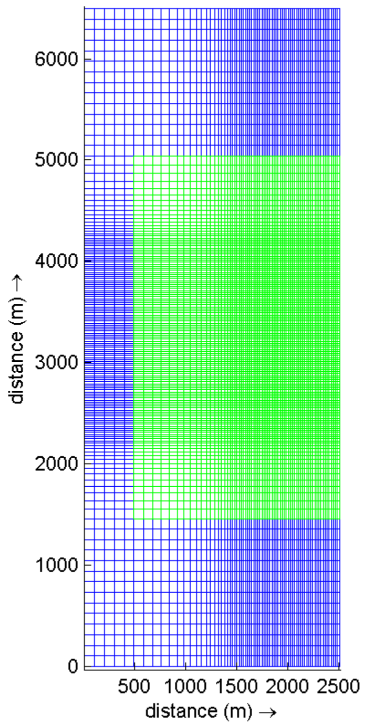


Figure 3-2 Cross-section of modelled area with inclusion of nourishment

Computational grids

For both Delft3D-FLOW and WAVE a computational grid has to be created. On the basis of these grids the model area is covered by a numerical scheme on which the model equations are computed. By limiting the amount of grid points the computational time can be made as small as possible. Though to get valuable information around your location of interest it is required to get a high enough resolution around the humps. To avoid boundary disturbances to reach the area of interest, directly around the nourished sections, the grid has to be large enough. For the wave computations a grid covering a larger area is applied so the waves will be fully developed when they reach the flow-grid. Waves will enter under an angle with the coast so the wave grid needs to be especially longer (in longshore direction). At the boundaries of the flow grid the waves will have influence on the flow field, this will cause some boundary disturbances so the flow grid has to be chosen sufficiently large as well. For this reason and to prevent that circulations due to nourishments will reach the boundaries, the flow grid has an extra length of approximately 1250 meter to the south and the north. Seaward this extra width is 500 meter.

In Figure 3-3 the computational grid and its properties are shown. The cell size increases with a maximum of 10 percent per grid cell (smoothness) to avoid instabilities due to too large step size differences. The maximum step size, at the boundaries, is set to be 100 meters. In cross-shore direction the area of interest is covered by a grid cell size of 20 meter increasing to approximately 50 meter at the seaward boundary. Shoreward from the nourishments the grid cells are of constant width, depth variations have a large impact on the hydrodynamics here and therefore a higher resolution has to be used. The Aspect ratio is the ratio between the M- and N-stepsize; a grid cell of 20-20 m has an aspect ratio of 1.



Wave-grid size (M*N)	71-161
Flow-grid size (M*N)	62-132
Nr. grid cells Flow-grid	8184
Min step size M-N (m)	20-20
Max step size M-N (m)	50-100
M-smoothness	10%
Maximum aspect-ratio	5.4

Figure 3-3 Computational grids and properties of computational grids

Depth averaged modelling versus 3-dimensional modelling

In the modelling approach it was mentioned that a depth averaged model is applied. The advantage of depth averaged modelling is that computations are only executed in one layer and the computational time will be significant less than in case of 3D modelling. The velocity is distributed logarithmical over the depth for computation of sediment transport.

Figure 3-4 shows the depth averaged Eulerian velocities at a cross-shore ray over the middle of a bar (solid line) and a hump (dotted line) at Y is 3250 m. The agreement within the scenarios is large, apparently the 3D (see Figure 3-7) and 2DH approach method give similar values for the depth averaged velocity. The difference in behaviour between the middle of the hump and the middle of the bar is considerably; apparently the onshore velocity at the bar is much less. In contrast with this the resemblance between the bar-head and the hump is much larger (Figure 3-5). The depth averaged velocities have comparable peaks, only the offshore behaviour is different.

Figure 3-6 shows how the velocity in 3D modelling is distributed over the depth for three different locations confirms the former conclusion. The behaviour at the bar-head and hump is similar (red and green). The blue line, the middle of the bar, shows large difference again. Averaging these lines over the vertical leads to the depth averaged values and are found in the latter two figures (X=1500 m).

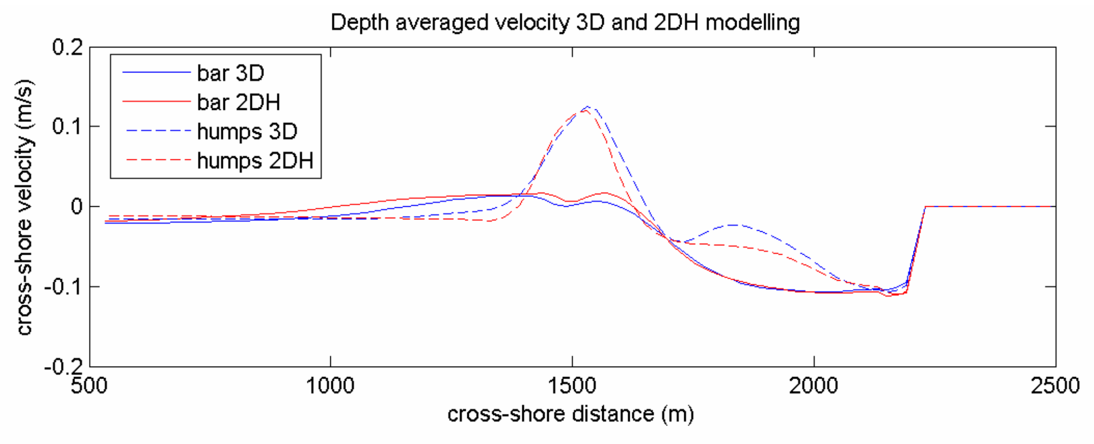


Figure 3-4 Depth averaged velocity for both 2DH as 3D modelling for a cross-shore ray over the middle of a hump (dots) and the middle of a bar (solid)

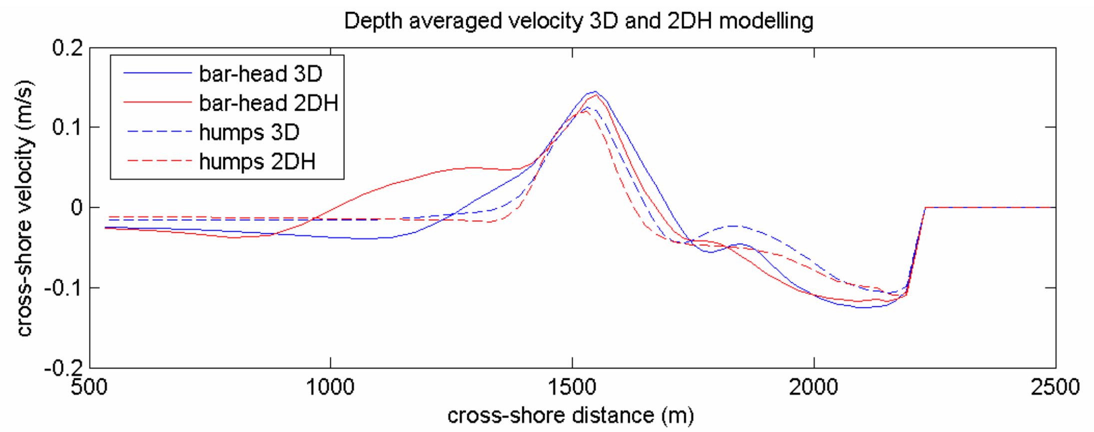


Figure 3-5 Depth averaged velocity for both 2DH as 3D modelling for a cross-shore ray over the middle of a hump (dots) and the tip of a bar (solid)

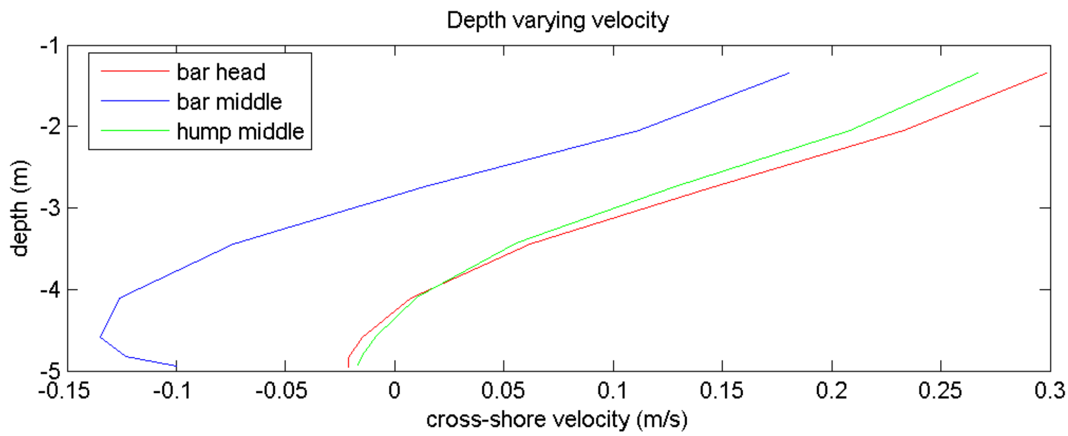


Figure 3-6 3D velocity profile for three different locations, at the middle of a bar (blue), at the tip of the same bar (red) and at the middle of a hump (green)

The latter analysis shows the resemblance between the 3D and 2DH modelling. On the other hand vertical velocity distributions at the nourishments are far from logarithmic but show similar pattern anyhow. Since this report is only analysing autonomous behaviour of bar and humplike nourishments the 2DH model is assumed to be a good representation of relative behaviour.

3.3 Boundary conditions

Wave schematisation

Waves are the main driving mechanism for circulations around nourishments, longshore current and sediment transport. In the first case only one constant wave condition is applied to give insight in the effects of wave forcing. The properties of this wave condition are not really typical for the Dutch coast but are representing an average storm and describe the acting processes in a good way. Of importance is the visualising of the effects so a good comparison is possible between the different scenarios and their hydrodynamics. In Table 3-1 the wave properties for condition 1, the reference condition, are summarized.

Table 3-1 Wave properties condition 1, wave height H_0 (JONSWAP) is the wave height entering the domain at the seaward boundary, T_p is the wave period, θ the angle of incidence with 270^0 being the direction perpendicular to the coast (Cartesian coordinate system), h_{cr} the waterdepth at the crest of the nourishment

	H_0 (m)	T_p (s)	θ (deg.)	h_{cr} (m)
Condition 1	2	7	250	3

By letting the angle of incidence vary and modelling various wave heights more understanding is obtained on wave influence in relation to the shoreface nourishments.

Wind

Wind is of little interest during the present study and therefore it has been decided to model without the influence of wind.

Water level schematisation

At the seaward boundary a constant water level is prescribed. At the lateral boundaries no water levels are specified but the water level gradients are. For the lateral boundaries the so called Neumann conditions are applied (Roelvink *et al.*, 2004). Neumann conditions determine the boundary solution by imposing the alongshore water level gradient. The problem with the conventional method of prescribing boundary conditions on the lateral boundaries is that the processes acting on the model, leading to velocity and water level distributions will lead to variations in cross-shore direction. These variations will lead to disturbances into the model. In this case the water level gradient, normal to the boundary, will be zero at the lateral boundaries. In later sections of this study different water levels are applied for a better understanding on the effects of water depth above the nourished sections. Water depth is varying from 3 to 5 meters above the crest of the nourishments.

3.4 Model Parameter settings

As the results can not be compared with real world values the only reference is to compare the different simulations and test results with each other. This paragraph gives attention to some parameter settings and used formulas for which a deliberate choice was made.

3.4.1 Hydrodynamic parameter settings

Since the model only uses implicit schemes the numerical stability is not restricted by the time step or the grid size and is always accurate to the second order. Explicit time integration on the shallow water equations is subject to a time step condition based on the Courant number for wave propagation. Especially around irregular closed boundaries the ADI-method can be inaccurate. In practical situations the Courant number should not be higher than 10 (WL | Delft Hydraulics, 2003a) however this is a rough estimate and the time step should be checked by executing a sensitivity test.

$$\sigma = 2c\Delta t\sqrt{\frac{1}{\Delta x^2}+\frac{1}{\Delta y^2}} \qquad \text{3-2}$$

$$c = \sqrt{gh} \qquad \text{3-3}$$

σ	=	Courant number (-)
c	=	wave celerity (m/s)
Δt	=	time step (s)
Δx	=	grid dimensions in x direction (m)
Δy	=	grid dimensions in y direction (m)
g	=	acceleration due to gravity (m/s^2)
h	=	local water depth (m)

Sensitivity runs show that time steps in the range of 6-24 seconds give approximately the same results for as well the waterlevel and velocity profiles as for the wave height at different locations (see appendix B-2). Time step limitation is not only related to wave celerity, but is also dependent on morphologic parameters. For accuracy the time step should be as small as possible, though to reduce computational time a larger time step is more efficient. The Courant analyses together with the sensitivity runs showed that a time step of 12 seconds satisfies.

With ν_H being the horizontal viscosity and D_H the horizontal diffusivity, both parameters will be set at the safe value 0,1 m^2/s. The viscosity is dependent on the local water depth. The FLOW model in combination with the Roller extension computes the viscosity every time step and is therefore self regulating. Especially for the location in between the humps it takes time to get a stable viscosity term, this is a result of the developing velocities.

Table 3-2 gives a summary of the important parameters that were used in the FLOW-module for the model.

Table 3-2 Parameter settings for FLOW-module

Parameter	Value	Unit	Description
Δt	12	s	computational time step
n	56	$m^{1/3}/s$	bottom friction (Chézy coefficient)
D_H	0,1	m^2/s	initial horizontal viscosity
ν_H	0,1	m^2/s	initial horizontal diffusivity
H_{dry}	0,4	m	threshold depth for drying and flooding
g	9,81	m/s^2	Gravity
ρ	1023	kg/m^3	water density

3.4.2 Sediment transport formulation

As was mentioned before, the sediment transport model is making use of the sediment online version of Delft3D. Flow and transport of sediments are computed at the same time and both are fed back for bottom updating simultaneously. In this study the sediment online version is used in combination with the transport relation formulated by van Rijn (van Rijn et al, 2004).

Delft 3D computes total change in sediment by summation of the change of the suspended load the change due to the suspended-load correction vector and the change due to bedload. Suspended sediment exchange with the bed is implemented by means of computing sediment sources and sinks near the bottom of the flow by using a reference height and a reference concentration. Bedload transport is computed in vectors at the waterlevel points and uses a different numerical scheme (Lesser *et al.*, 2004).

For the model TRANSPOR2004 (van Rijn *et al.*, 2004) is used. TRANSPOR2004 is a newly implemented transport formulation in the Delft3D-online version and is mainly an update of the TRANSPOR1993 formulation (van Rijn., 1993). The TRANSPOR formulation calculates the sediment concentrations under currents and waves by including an analytical, semi-empirical model of the diffusion of sediment in the vertical. In contrast with other formulations this formulation is including asymmetry effects. The main advantages of TRANSPOR2004 above TRANSPOR1993 formulation are based on the inclusion of predictors for the bed roughness and the suspended sediment size in the vertical.

The current FLOW-module makes use of the Generalised Lagrangian Mean method which includes wave induced mass-flux. The GLM velocity corresponds to the combined motion of currents and free surface waves and is used for sediment computation (Walstra *et al.*, 2000). With depth averaged modelling (2DH) onshore transports are far overestimated, as there are no components compensating this onshore drift. For this model the Eulerian velocities are applied for the computation of sediment transport.

3.4.3 Calibration process

The TRANSPOR2004 model makes use of some user-specified calibration values to fit the transport properties to the local situation. For the current model there is no reference situation and no validation data exist to calibrate the model. In the context of the development of the nourished scenarios it is of importance to get some good understanding of the sediment processes and the influence of the largest variations. The main objective is not to know the exact numbers and transport rates but to get a first indication of the influence of the varying flow field in the vicinity of these nourishments. Therefore the calibration of the model is executed by using an existing 3D-model and the calibration values are determined in a rough way.

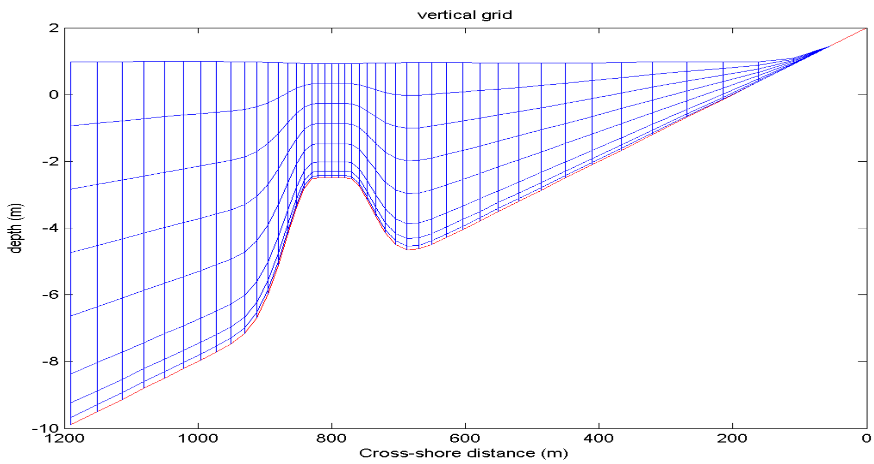


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Figure 3-7 Vertical grid for 3D simulations

The procedure for the calibration process is as follows. Making use of a profile model makes it possible to determine transport values in an efficient way. An undisturbed sloping bottom of 1:100 is exposed to waves propagating towards the coast. A first step describes the 2 dimensional distribution of flow over the vertical, computed on the vertical grid according to Figure 3-7.

For the transport formulations the transport parameters used for the Egmond model were taken for calibration of the model (Walstra, 2004). This model showed some good results and the situation was typical for the Dutch coast as it is schematised in this study. By applying the same factors (Table 3-3) from the 2-dimensional profile model applicable transport values are expected to result, forming the reference for the calibrating of the depth-averaged profile model. The shown parameters are describing the behaviour of transport in a quantitative sense, making distinction between bedload and suspended load transport and wave related and current related transport.

Table 3-3 Calibration factors for different models

	Egmond	2D-profile	1DH-profile
Sus	1	1	0.8
Bed	1	1	0.7
Susw	0.2	0.2	0.2
Susb	1	1	1

In Figure 3-8 the suspended and bedload transports for both profile models are plotted. By comparing the transports and varying the factors both individual transports were determined. The peaks are of approximately similar magnitude. Clearly visible from Figure 3-8 is that bed load transport is mainly determined by the orbital motion and is directed onshore. The suspended load is dominated by the current effect and is directed in offshore direction in this case. The positive peak for the suspended load for the 2D-profile model shows the domination of orbital motion in this part of the nearshore zone for the suspended load.

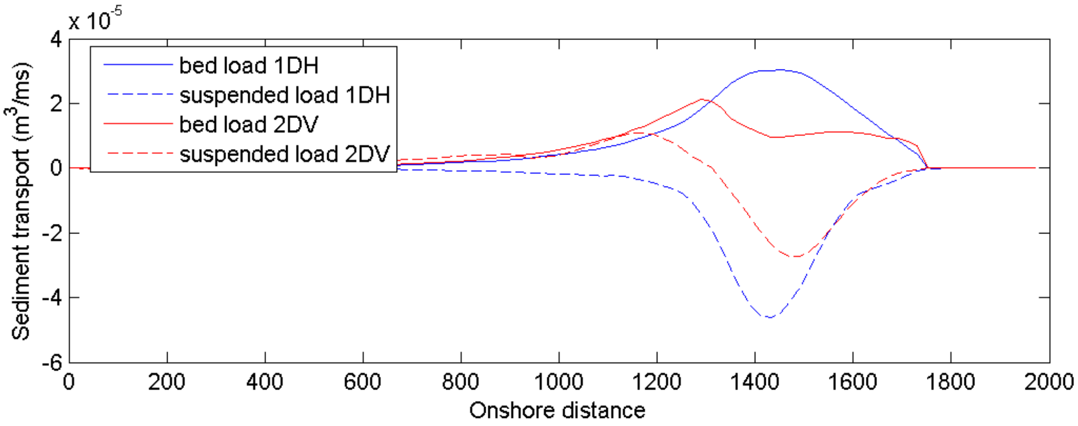


Figure 3-8 1DH modelling (blue) and 2D profile model (red), suspended load (dotted) and bed load (line)

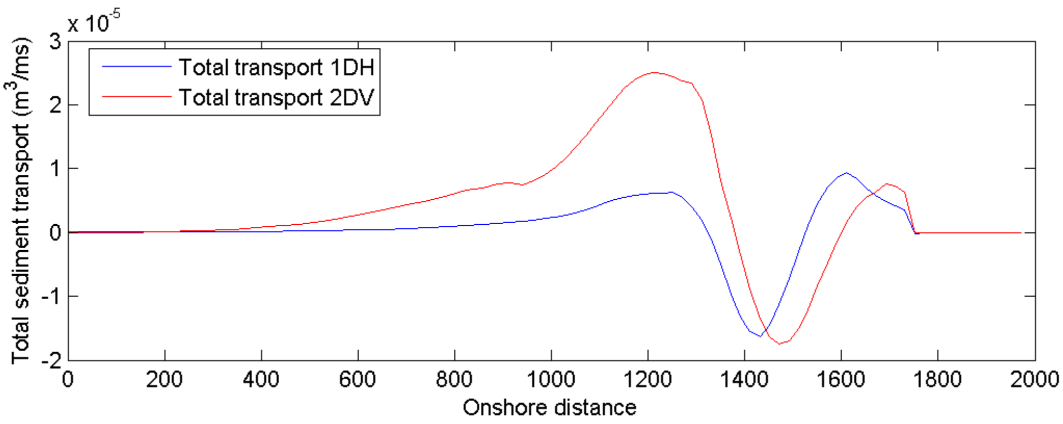


Figure 3-9 Total transport for the 2D profile model (red) and the depth-averaged profile model (blue)

On first sight, the figures show some large differences. Transport profiles have different peak values and even the sign is different. Apparently the method of using the 2DV settings as reference for the 1DH model is not so successful. A deliberate choice has been made for the transport parameters as they are shown in the above. The peak values are similar, meaning that the bed load and suspended load have a comparable share in the total transport for both the 2DV and the 1DH profile model. Mainly the wave induced circulations and currents are expected to be of importance, these are described by the parameters sus and bed. The contribution of wave mass flux is described by susw and bedw and has considerable influence on transport. Earlier studies showed that a value of 0,2 for susw is reasonable.

Morphodynamic behaviour still showed an offshore shift of the shoreline. Apparently the processes in the breaker zone are too far from its equilibrium and the depth averaged model is not describing the processes in the breaker zone properly. It was decided to work with the described parameter settings (Table 3-4). These parameters showed a plausible description of nourishment behaviour. By subtraction of the zero-situation, being the model area without nourishment, a better representation is given. In this way the effect of the nourishment is only described qualitatively. Appendix B-3 shows a number of parameter configurations and their impact on the transport. Finally the main input parameters for the transport model are the following.

Table 3-4 Parameter settings transport model

Parameter	Value	Unit	Description
D_{50}	0,2	mm	mean sediment particle diameter
D_{90}	0,3	mm	sediment particle diameter
Sus	0.8	-	Tuning parameter suspended load
Bed	0.7	-	Tuning parameter suspended load
Susw	0.2	-	Wave related suspended load parameter
Bedw	1	-	Wave related bedload parameter
SedThr	0.5	m	Minimum depth for sediment computations

Settings of interest for the morphodynamic behaviour, like the morphological acceleration factor and the spin-up interval will be described in Chapter 6, the morphodynamic analysis. This chapter will deal with more analysis on parameter settings and their effect on morphological development for the whole area and confirm that the parameter settings are not ideal and the 2DH model shows some unreliable behaviour in the breaker zone.

4 Hydrodynamic analyses of humplike nourishing under wave exposure

4.1 Introduction

In the chapters following an extensive analysis is given on the hydrodynamic processes in the coastal zone in the vicinity of nourished humps. As was mentioned in Chapter 2, the presence of nourished bars on the shoreface has a great impact on the hydrodynamics in this zone and therefore these bars behave in a complex way. Nourishing the shoreface with humps in stead of one elongated bar only makes the processes more complex and getting insight in the hydrodynamics is therefore of great importance. By analysing the influence of different types of nourishments on the hydrodynamics, it is possible to evaluate which variations will result in the most efficient nourishing of the beach zone.

Waves form the most dominant factor for the transport of sand and the redistribution of the nourishments into the littoral zone. Waves breaking on humps will cause extra currents, which will bring sand into suspension. Following paragraphs describe the influence of varying hydrodynamic conditions such as wave height, angle of incidence and waterdepth above the nourished sections, on the hydrodynamics.

4.2 Hydrodynamic characteristics of shoreface nourishments

Different wave conditions like variation of wave height, angle of incidence but also the amount of water above nourished humps and bars influence the hydrodynamic characteristics around the nourished sections. The evolution of nourishments in an actual situation is a summation of all effects of different hydrodynamic conditions they are exposed to, all having their own impact and timescale on morphodynamics. In this paragraph the focus lays on the hydrodynamic characteristics of three nourishment configurations and the influence of variation of the wave conditions.

The reference wave condition (Table 4-1) is chosen in such a way that the processes, which influence the sediment transport, are clearly recognisable. These properties and the different nourishment scenarios described in Table 4-2 are the basis on which the wave conditions and nourishment dimensions will vary during the course of this chapter.

Table 4-1 Reference wave condition

	H_0 (m)	T_p (s)	θ (deg.)	h_{cr} (m)
Condition 1	2	7	250	3

For a first analysis of the hydrodynamics around nourishments some simple bathymetries will be used. The bathymetries represent the undisturbed situation, the individual effect of a hump on the hydrodynamics, the effect of a number of humps in a row and the conventional elongated bar as a reference for the efficiency. In the last two cases the total nourished length is similar.

Table 4-2 Reference bathymetries for hydrodynamic characteristics

	Number of nourishments	Length of crest (m)	Mutual Distance (m)
Bathymetry 0	0	-	-
Bathymetry 1	1	50	-
Bathymetry 2	1	1000	-
Bathymetry 3	3	100	200

Breaking of waves and inducement of currents in the nearshore zone have great impact on the transport of sediment and it is of importance to understand them well. As already mentioned, the occurring processes are complex, waves interact with the bottom and generate currents in longshore and cross-shore direction. These currents on their turn have their influence on the wave development. This paragraph deals with the generating of currents and variation of wave properties around nourishments and their result on the sediment concentration and sediment transport. The following aspects will be dealt with hereafter.

- Wave development and their effect on the waterlevel and current generating;
- Development of currents and velocity patterns and the cross-shore and longshore components of these velocity vectors;
- Sediment concentration patterns as a result of these currents and waves;
- Transport of sand, both in cross-shore and in longshore direction.

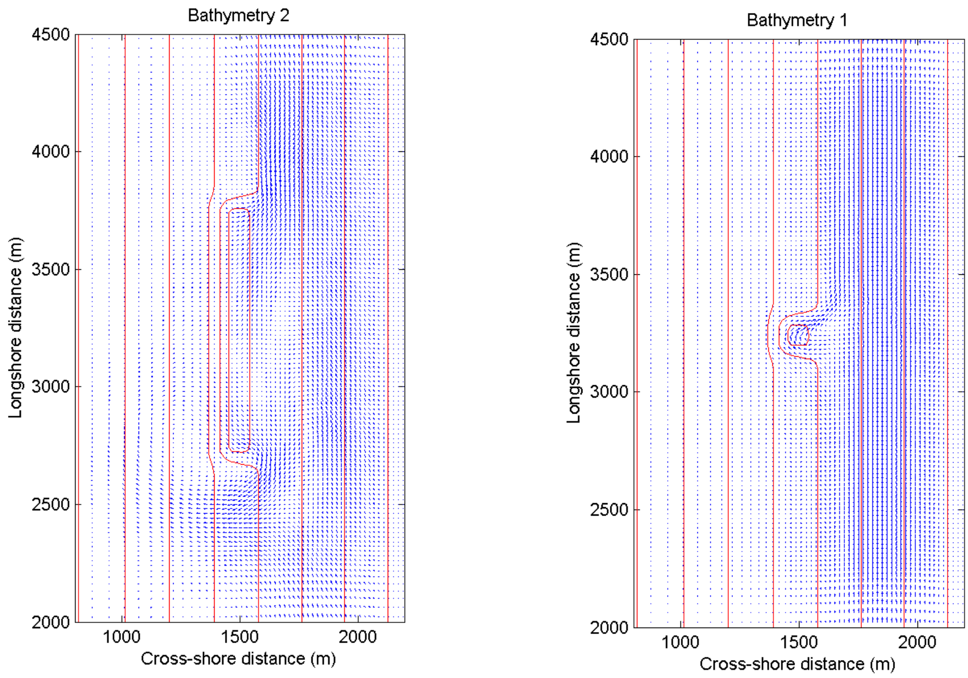


Figure 4-1 Depth-average velocity patterns as a result of condition 1 for 1) the conventional nourishing method and 2) a single nourished hump of 50 by 50 meter

In Figure 4-1 the development of the velocity, averaged over the depth, is visualised. In the left plot the conventional nourishment is shown by the red contour lines the right plot shows a single hump at the same offshore distance. Both are exposed to condition 1 (see Table 4-1), the resulting circulations and currents are visualised by blue vector arrows. Some first effects, clearly visible, are discussed.

- In the undisturbed situation a wave-induced longshore current is generated from south to north. The magnitude of this current depends on the wave height and the angle of incidence. The nourished sections are, in this case, located just outside the longshore current. The longshore current is influenced by the nourishment induced currents.
- In the lee zone (eastward) of the nourished section this current is interrupted. Due to wave breaking at the crest of the nourishments the wave impact is less and the longshore current shifts onshore. This effect is most clear in the situation with the nourished bar.
- Waves breaking and propagating over the crest of the bars leads to an extra generated current in the vicinity of the nourished sections. This current does not only develop in the same direction of the wave propagation but has more complex patterns. As an example at the southern tip of the bar (left plot) a rip current is generated to the south as at the northern part the flow is directed in northern direction. On the hump a current is induced in the direction of the wave propagation. These effects are the main aspects of interest and will be dealt with extensively in the further sections.

4.2.1 Wave induced currents

In case of shallow water the water particles are describing an orbital motion resulting in shear stresses on the bottom acting on the sediments. From the water surface down to the bottom the vertical component of this orbit is reducing. The amplitude of the orbital velocity near the bottom is dependent on the wave properties (H_s and T_p) and the waterdepth. On its turn the wave height itself is directly related to the waterdepth as well. Breaking waves in the surf zone and on shallow water have an even more intense impact on sediments brought into suspension. Distribution of sediments is dependent on currents taking the sediments. As shown in the above currents are generated in the surfzone of the coast and, more interesting for this study, in the vicinity of the nourishments. In Figure 4-2 the wave heights are shown in combination with dissipation of energy. It illustrates the effect of the nourishments on the waves, breaking and disturbances of waves around it.

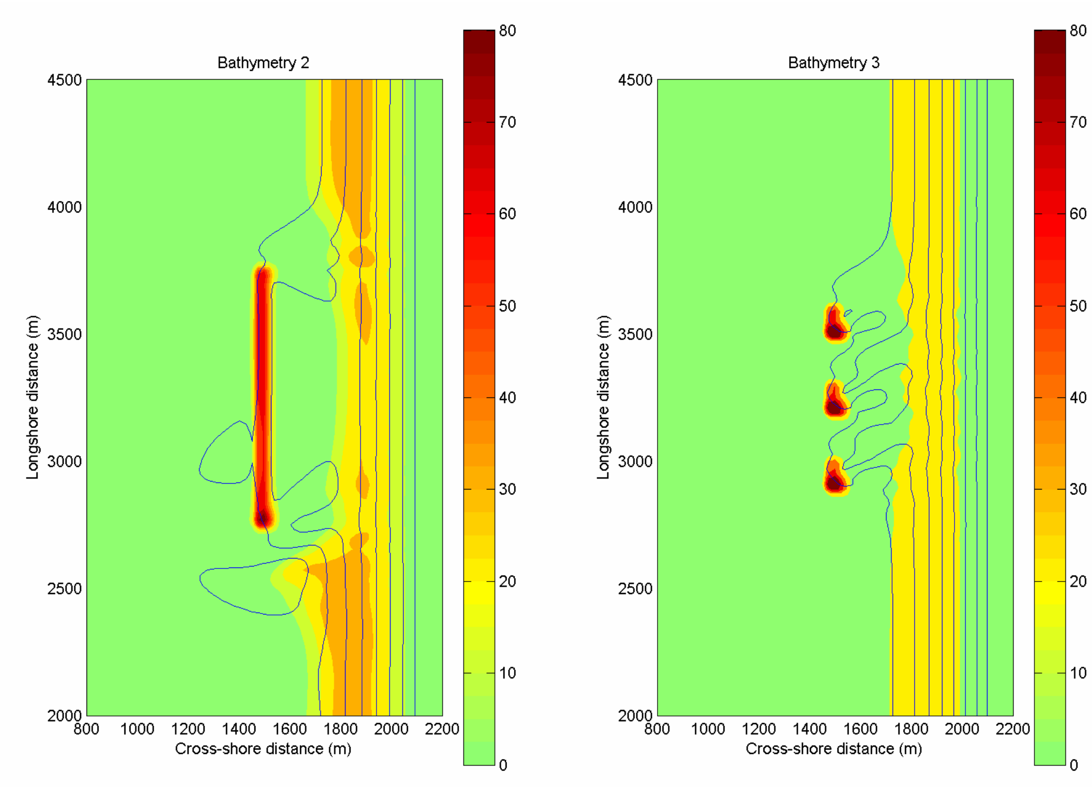


Figure 4-2 Wave dissipation (W/m^2) plotted together with the contour lines for wave height (m)

Wave energy is dissipating on the crest of the nourishments and in the surfzone as an effect of wave breaking. Dissipation of energy is compensated by set-up of water leading to waterlevel variations and mass-fluxes resulting in circulations and currents. In Figure 4-3 the resulting waterlevel variation is illustrated. It is clear that for the bar nourishment the dissipation of wave energy results in a better developed waterlevel rise. In the middle of the bar it increased with app. 0,03 m. The longshore generated currents are most developed at the bar heads, here the waterlevel gradients are maximal. This effect is the cause of the strong horizontal circulations which will be discussed later.

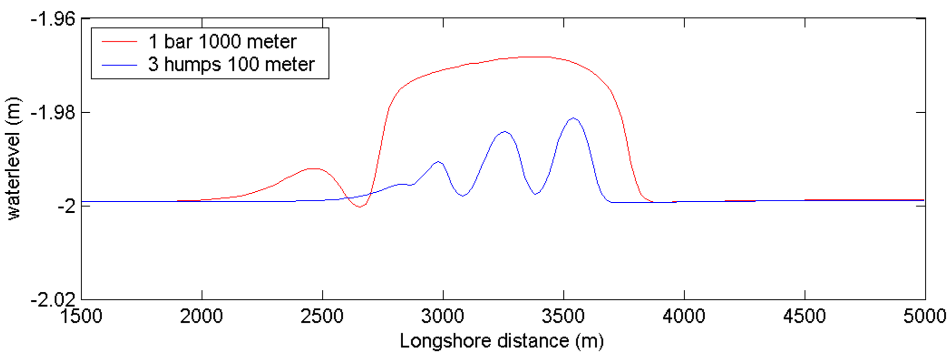


Figure 4-3 Water level variation on crest of nourishments

At the southern tip of the bar waves are dissipating more energy, here the current related to the set-up is directed in opposite direction with the wave propagation. Apparently this leads to higher waves and thus more energy dissipation. The same effect is visible for humplike nourishments. The waterlevel is increasing here as well, leading to longshore directed currents at the crest of the humps. A clear difference of dissipation magnitude is seen on the crest of the humps. This results into a separation of flow direction on the hump crests.

In the lee zone of the nourished sections waves are less high as a result of the breaking at the nourishments. As a result less dissipation is seen in the nearshore zone. In the direct vicinity of the nourishment some effects are worth mentioning:

- The rip current to the south of the nourished bar is causing an increase of wave height Waves are pushed together and grow; in coherence with this the waves are getting flatter where the currents are propagating in the same direction. This effect of wave-current interaction acts at the offshore side of the nourishment where the rip current is attracted by the waves and returns to the bar again;
- At the tips of the bar-nourishing waves are slightly higher as a result of current refraction due to circulations. This is seen in Figure 4-4, the green and dark blue line represent the wave heights at the tips of the bar. In comparison with the middle section, the red line, the waves are somewhat higher. The purple line shows the breaking of waves at the middle hump and the effect of waves propagating in between the humps leading to increase of wave height again.

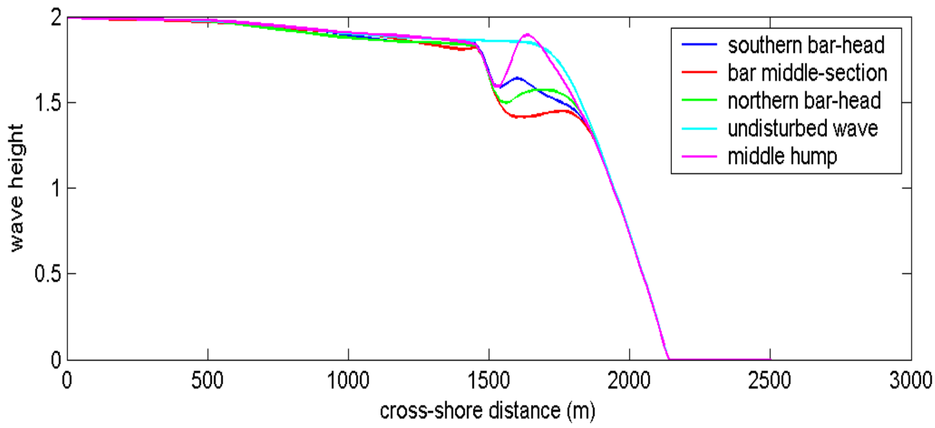


Figure 4-4 Wave height variation on different locations for the two nourishment scenarios, wave heights are plotted at the different cross-shore rays with a constant height for the seaward boundary

4.2.2 Longshore and cross-shore velocities

For a better idea of the directions of the currents and their magnitude, the longshore and cross-shore velocities are plotted at 4 rays parallel with the shore, see Figure 4-5. Distances of the rays are chosen deliberately in the vicinity of the bar and in the breaker zone. In later sections, especially the onshore ray distances vary, depending on the data which are of interest.

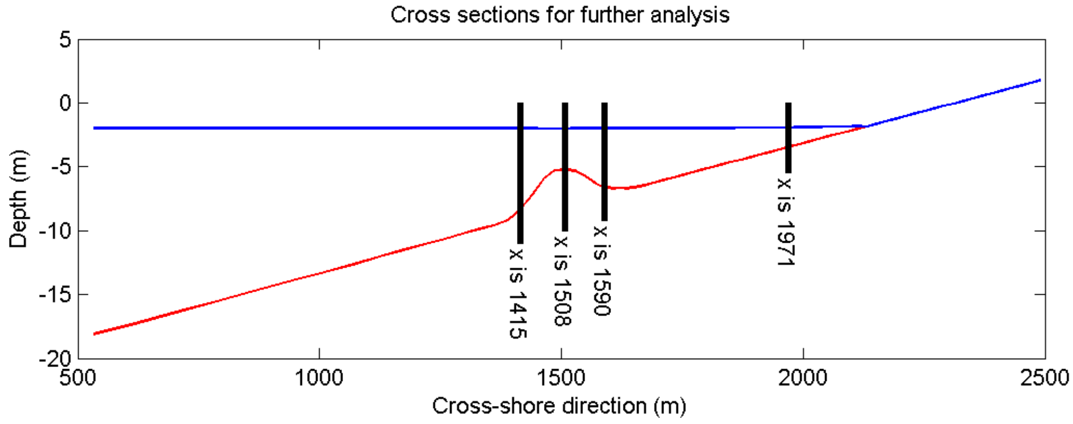


Figure 4-5 Cross sections on which data are plotted, x=1415 is just offshore from the crest, x=1508 is on the crest, x=1590 just onshore from the crest and the last one is in the breaker zone.

The comparing of the different bathymetries and their influence on the velocity profiles in Figure 4-6 and Figure 4-7 give a good indication on the influence of the nourishments on different locations in the area and especially the differences between the scenarios. Some first conclusions are made and summarized hereafter. All red lines represent the bar-nourishing, the green lines a 3-hump scenario (humps 100 meter long and gap width of 200 meter) and the blue line a single-hump scenario.

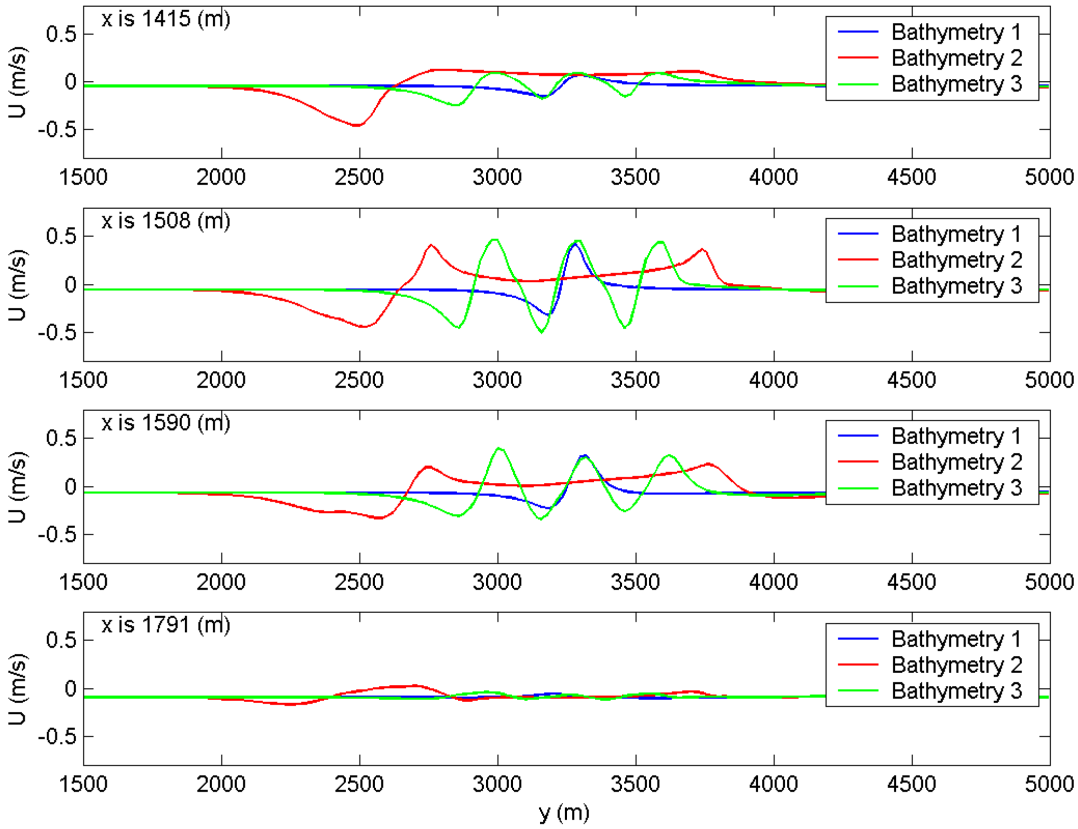


Figure 4-6 Cross-shore velocities at cross-sections, x=1415 is just offshore from the crest, x=1508 is on the crest, x=1590 just onshore from the crest and the last one is in the breaker zone.

- The onshore velocities are largest at the crest of the nourishments and just north of them, here the shear stress is increasing as a result of dissipation of wave energy partly leading to a mass-flux of water;
- The offshore velocities are largest southward of the nourishments and in between the humps in the case of the humps. The return current is stronger and reaches further for one elongated bar than in the case of 3 humps, this is the result of the better balanced set-up at the elongated bar;
- Cross-shore velocities at the crest of the humps are more constant in magnitude compared to the conventional nourishment. The cross-shore properties of the single hump are similar to the properties of the middle hump for the scenario with the three humps; apparently the mutual influence of the humps on the cross-shore velocities is not so large. Though the offshore velocity for the single humps is smaller as a result of the upstream generated current;
- At the crest of the elongated bar the cross-shore velocity is largest at the tips, this is mainly caused by the parallel waterlevel gradients here leading to currents in longshore and cross-shore direction. Waves influence the direction of the resulting currents;
- In the surf zone, close to the shoreline the cross-shore velocities decrease, influence of the nourishments is visible. Especially for the bar a clear distortion is present at the upstream, southern, section. Here the effect of the circulations is clearly visible;

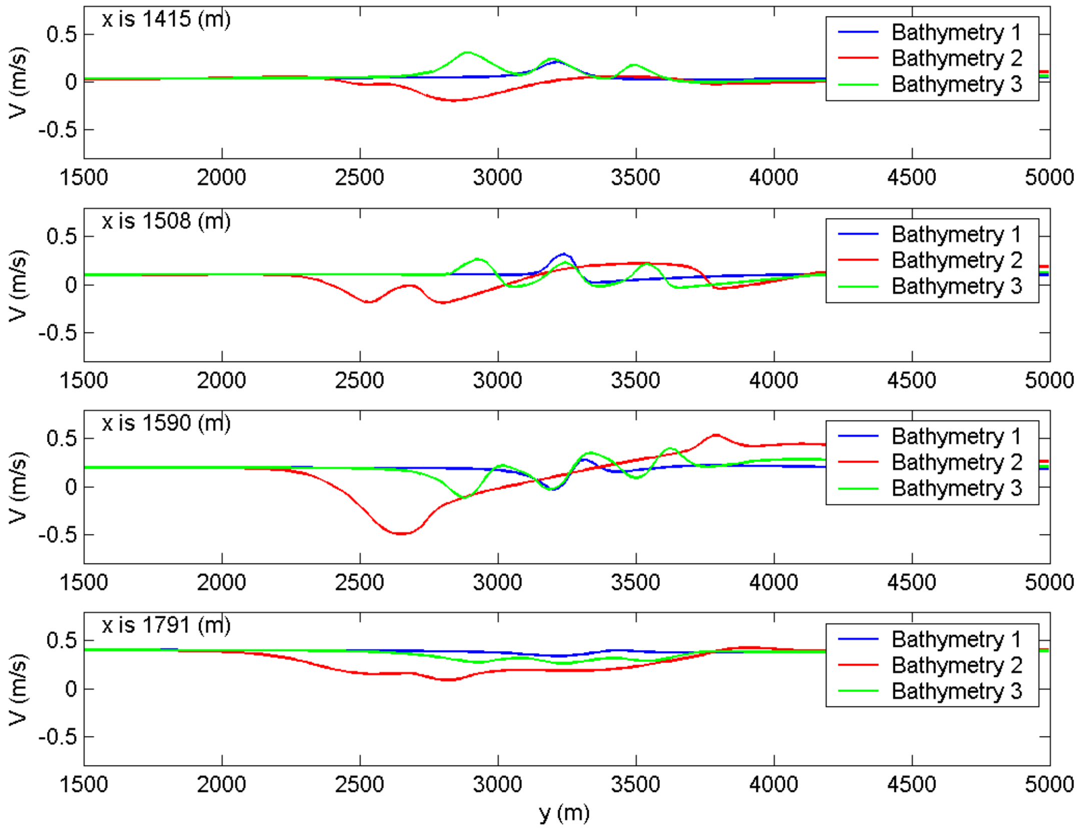


Figure 4-7 Longshore velocities at cross-sections, x=1415 is just offshore from the crest, x=1508 is on the crest, x=1590 just onshore from the crest and the last one is in the breaker zone.

- In longshore direction the largest influence is visible just onshore of the crest. Here the set-up causes the current along the crest. For bathymetry 2 it is clear that this current splits approximately at half the distance of the crest (in longshore direction) where it flows out in both directions;

- In the case of the humps the same effect is shown at the southern hump. At the second and the third hump this effect is still visible but is disturbed by the northerly directed current, which is generated at, from south to north, the first and the second hump. This causes smaller velocities in longshore direction;
- Onshore of the most southern hump a southward current is generated as result of the waves propagating in between the humps. These break and cause waterlevel variations leading to the mentioned current;
- Onshore from the crest a tendency is visible for the longshore velocities for the hump scenario. The averaging of the longshore current for the 3 humps is showing a similar line with that of the elongated bar, meaning that in summation the humps behave as a elongated bar in longshore direction;
- Offshore of the nourished bar a southward directed current is present. The circulation southward of the nourishment is heading back to the nourishment offshore. As it reaches the nourishment again it is attracted by the existing currents and waves refract. The largest component of the current is southward and is a result of the existing set-up at the bar (see Figure 4-8);
- In the surfzone, there where the waves induce the longshore current from south to north, the longshore current is disturbed. One reason for this is the sheltering effect of the waves; less high waves enter the coast in the lee zone. This results in a shift onshore of the longshore current due to the breaker line moving onshore and a less strong current. is the result. On the other hand opposite currents cause contraction of currents and thus stronger currents (see Figure 4-8). This effect is mainly visible with the elongated bar;

In appendices C-1 the result of the nourished scenarios is visualised over the whole area, in combination with contour lines for the concentration of sediment which are in suspension. By subtraction of the zero-situation the net impact of the nourishments is obtained (appendices C-2). Remark for these plots is that a negative value does not have to mean that current is directed in this way.

4.2.3 Concentration of sediments

Figure 4-8 gives a first indication of the sediment concentrations in combination with the longshore current effects and makes clear that concentration is highly related to the velocity profile. The formula for sediment transport describes the instantaneous concentration caused by a combination of the depth-averaged velocity in longshore and cross-shore direction and the near bed orbital velocity under waves. The figure below shows a clear increase of sediments in the vertical on top of the crest. Just south of it were the velocities are high, in the rip current, the sediment concentration is not particularly high as a result of the increasing water depth. In the lee of the nourished sections it is clearly visible that the concentrations decrease and the longshore current shifts onshore. For the left plot a concentration increase is present, there where the current is contracting.

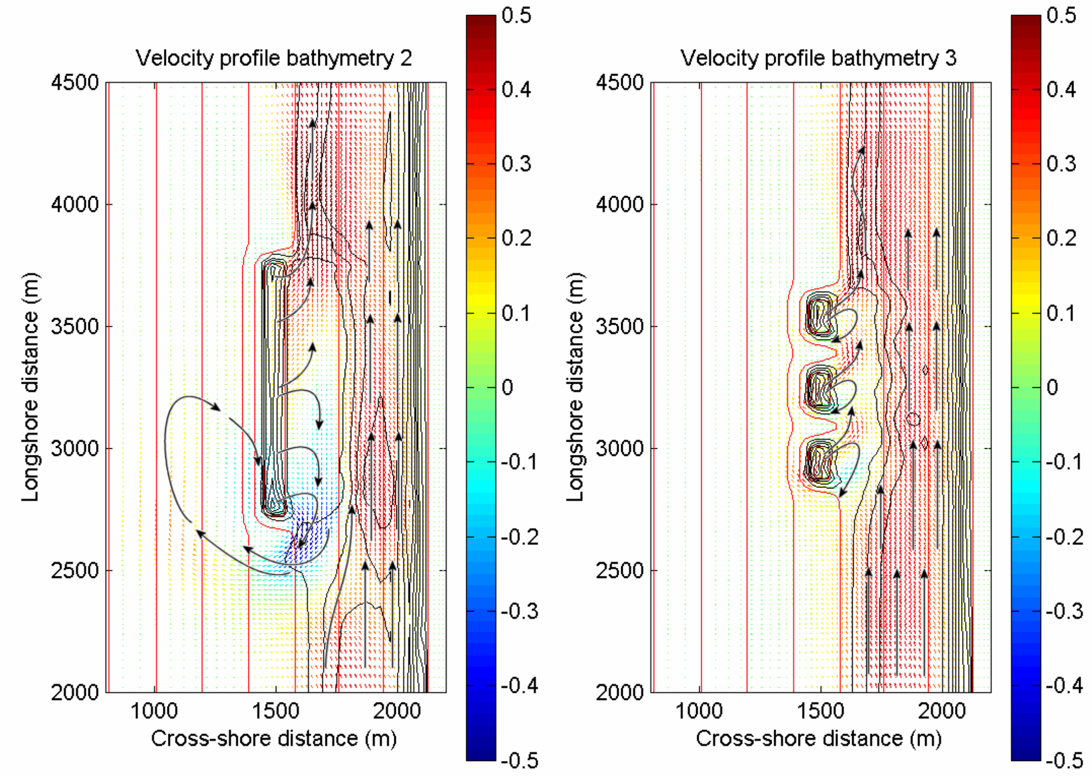


Figure 4-8 Velocity vectors with the longshore component described by colour variations and arrows giving a rough indication of overall processes, the black contour lines denote the different sediment concentration levels.

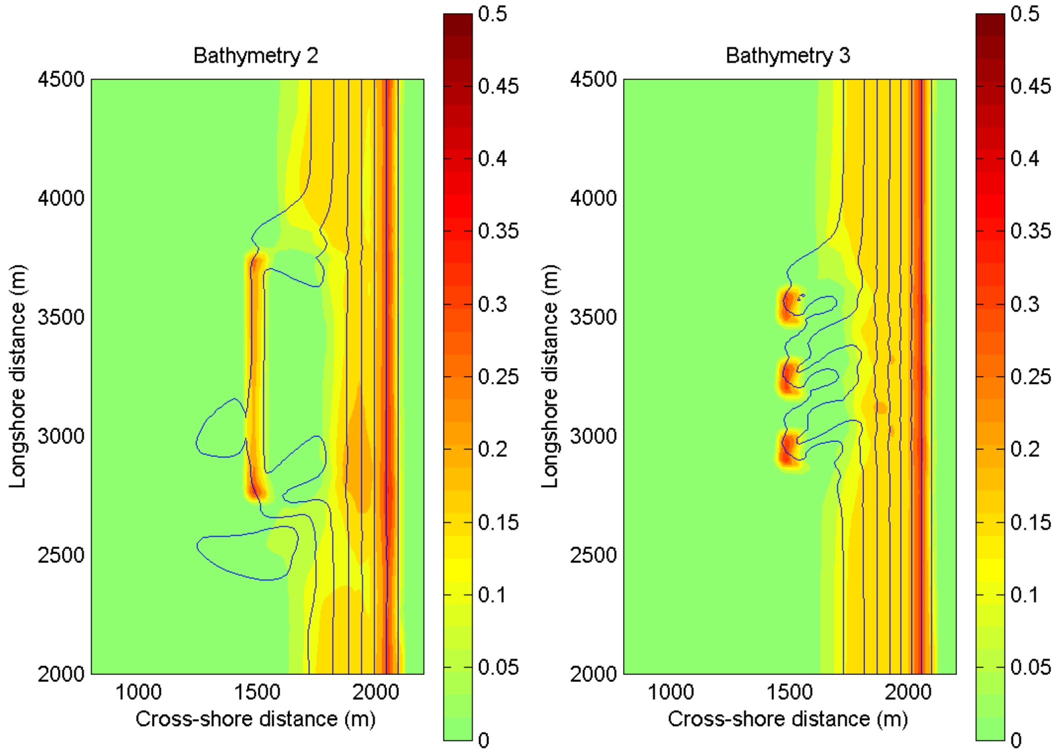


Figure 4-9 Concentration (m^3/m^3) plotted together with the contour lines for wave height (m)

In Figure 4-9 the concentration levels are plotted together with the wave heights. The concentration values are again visualised at the cross-section and visualised in Figure 4-10. Some conclusions from these plots are:

- At the crest the concentration levels are significantly higher than at the sections just on- and offshore, here waves bring sand into suspension and velocities are highest;
- Important is the concentration level at the southern side of the humps and bar. Rips are present here and cause high velocities offshore. The increasing depth results in less wave impact at the bottom and low values for the concentrations of sand. This has as positive effect that the rip currents do not generate large offshore transports;
- Again the differences between the concentration peak of the single hump and the middle humps for bathymetry number 3 are negligible, for further analysis only the ‘multiple humps scenario’ will be used as the analysis of them both give comparable results;
- The concentration level at the humps is of a more constant level than at the bar where only at the tips a high concentration is seen. This together with the onshore velocity is the main effect resulting in the tips of the nourished bar migrating onshore faster than the middle section;
- As the cross-sections reach onshore, more sediment is in suspension. In the lee zone of the nourished sections there is some disturbance. The clearest this is for the bar nourishment, here a decrease of concentration is caused by the sheltering effect and as a result the smaller longshore current. To the south the concentration increased as a result of contraction of the current due to the opposing currents. These opposing currents are the cause of a concentration decrease even more south.

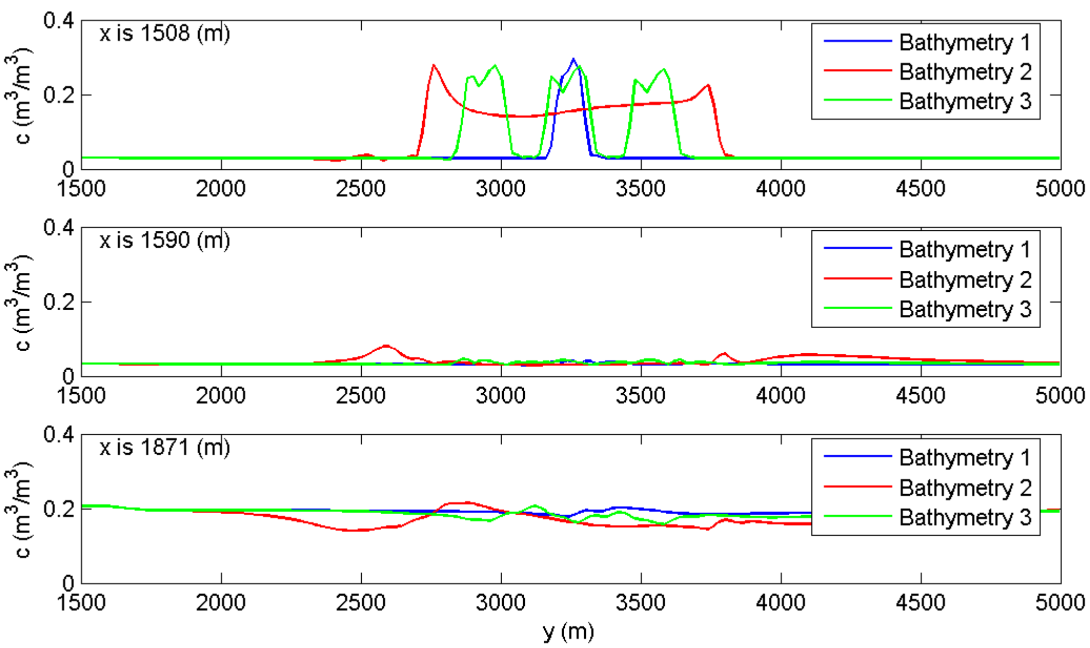


Figure 4-10 Sediment concentrations at cross-sections, x=1508 is on the crest, x=1590 just onshore from the crest and the last one is in the breaker zone.

Differences in longshore sediment concentrations and currents will result in erosion and sedimentation and thus variations in the coastline. From the analysis above it can be concluded that the onshore transport due to the nourished sand is expected to be more efficient in case of humps than for one elongated bar, which is the first indication that the hypothesis might be right. The bar will cause more disturbance nearshore and thus more variation in the shoreline. In case of the bar nourishment objective can be to trap sand in the lee zone and increasing width of the coast. The following sections will give more attention to sediment transport and erosion and sedimentation of sand and the influence of bar length and gaps between humps.

4.2.4 Transport of sediments

The hydrodynamic properties as they were discussed in the above showed some promising results. Sediment transport is the movement of sediment particles and is therefore dependent on the transport of water in the form of currents and the concentration of sand being in suspension as they were analysed. In this part first the cross-shore and longshore transports will be discussed, first by showing their magnitudes on the rays used before and later by showing the effect of the nourished sections on the sediment transport.

Cross-shore

Figure 4-11 shows the sediment transport in cross-shore direction. On the x-axis, again, the longshore location is given; the four plots show the longshore transports on different distances from the shoreline. The y-axis represents the sediment transport in volume sand per meter per second in cross-shore direction. There is mainly cross-shore transport at the crest of the nourishments. More onshore and offshore the transport rates decrease fast. Only little impact is seen just onshore of the nourishments. Velocities are still high here, though as a result of the increasing depths and milder waves the concentrations are low and the transport is minimal. The 3 humps show a strong onshore transport, stronger than the onshore transport of the bar-nourishment. On the other hand the offshore transports are higher here as well so the net result is smaller as it will be seen in the following figure.

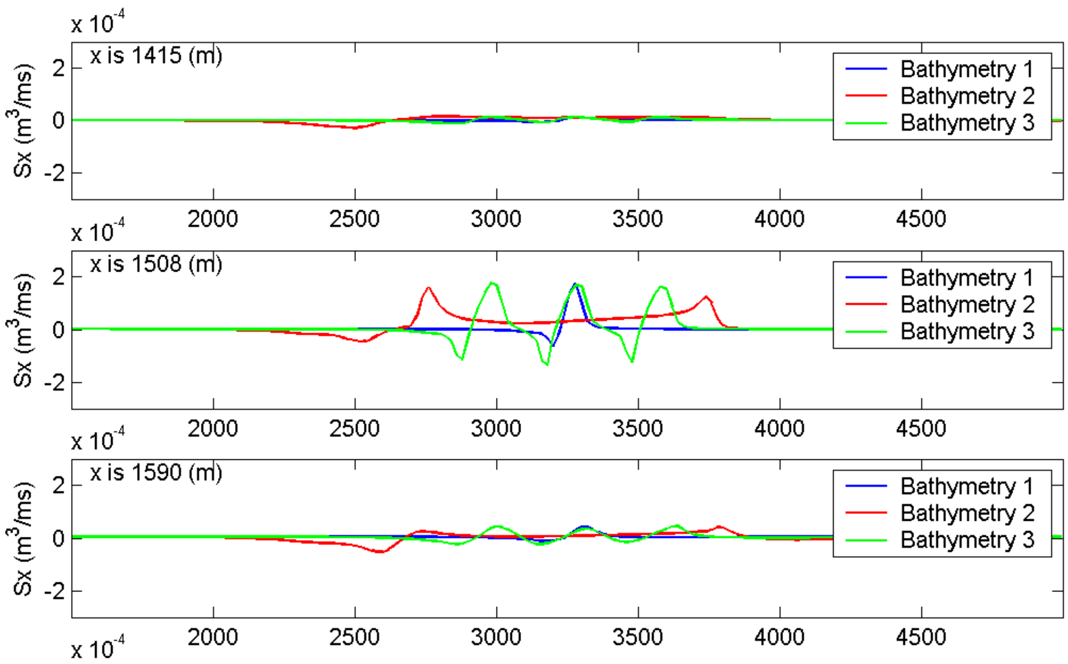


Figure 4-11 Cross-shore transports in m^3/ms

In comparison with the cross-shore transports seen on the crest of the nourishments the sediment transport in cross-shore direction in the surf-zone seems negligible. As later parts of this study will show, variations in the surf-zone will result in morphological changes on longer time scales as well. For this chapter and the following one only initial transport is taken in account, for which this surf-zone transports have little effect in cross-shore direction.

Integration of the cross-shore sediment transports in longshore direction over the full domain length, results in the total cross-shore transports. By subtracting the reference situation, being the model without the implemented nourishments the net result is obtained. Figure 4-12 shows the transport per scenario, integrated over the longshore rays as they are defined by the Flow-grid, with the autonomous behaviour of the model without nourishments in light blue. The figure shows how the differences with the autonomous situation get bigger onshore with more nourished amount of sand. Figure 4-13 shows the integrated cross-shore transport with subtraction of the situation without nourishments.

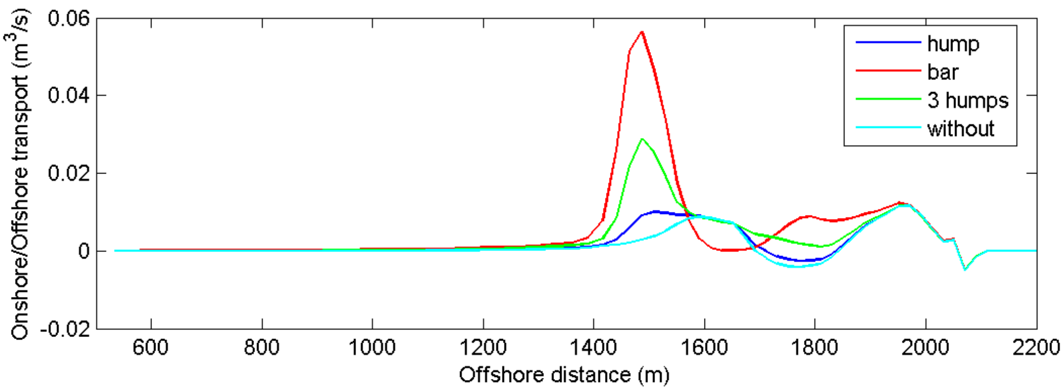


Figure 4-12 Cross-shore transport integrated over the longshore length of the domain.

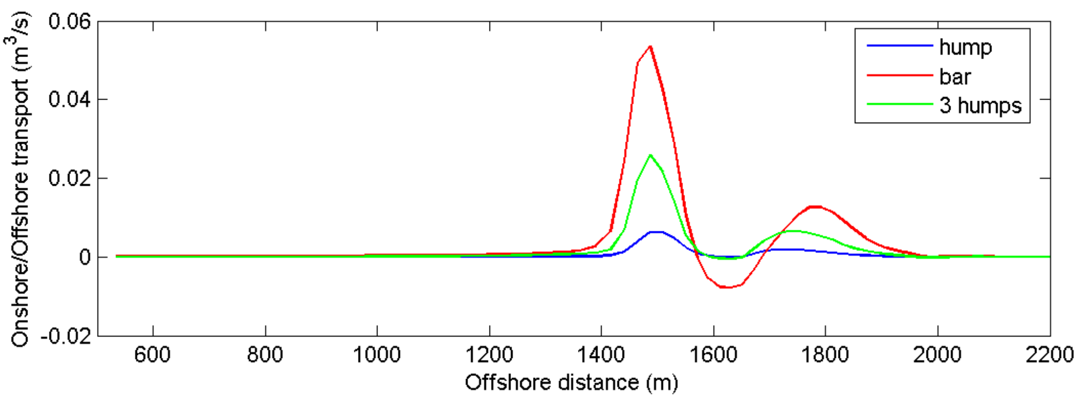


Figure 4-13 Net cross-shore transports (subtraction of situation without nourishing) integrated over the longshore length of the domain

The effect of the nourished sections is clear by the onshore transport peaks at x is 1500 meter. The more sand is nourished the higher the peak is. Big differences are seen onshore of the nourished sections (1600-2000 meter). The three plotted lines in Figure 4-13 mainly show relative differences as negative values do not have to mean that transport is directed offshore (net transport). Remarkable is that the scenario with the three humps has a net onshore transport on every distance from the shoreline, in contrast with the bar-nourishment, which shows a strong decrease of transport just onshore of the nourishment (x=1600 m). The offshore transport for the bar nourishment is mainly generated by the large rip south of the nourished section. The onshore transport increasing in the surfzone in case of the elongated bar is due to the contraction of the longshore current.

Objective of this study is to determine the efficiency of the implemented scenarios. One part of the efficiency is the sediment transport as a ratio of the nourished sand. By using a smaller amount of sand for a larger relative result, dredging costs might be lower than for the conventional method. It is clear that the nourished bar uses much more sand than the scenario with the 3 humps. The total amount of sand per used scenario is as follows:

Table 4-3 Amounts of nourished sand

	1 hump	**3 humps**	**1 bar (1000 m)**
Sand volume (m^3)	70.000	270.000	510.000

Figure 4-14 is the result of the total of cross-shore transports per longshore ray per nourished amount of sand. In comparison with Figure 4-13 the lines are more comparable now. Remarkable is that the blue and the red line are similar; obviously the number of humps did not make any difference for these cases. This will be investigated in more detail in the next chapter. Comparing the 3 humps with the bar leads to the conclusion that the onshore transport for the bar is larger but that the offshore transport for the bar is significantly larger as well. By increasing the mutual distance between the nourished humps the offshore rips will probably decrease and move to deeper water instead of being attached to the humps, the offshore component on the crest will decrease and the result will be better overall. The aspect of hump lengths and mutual distance will be dealt with more elaborate in the following chapter.

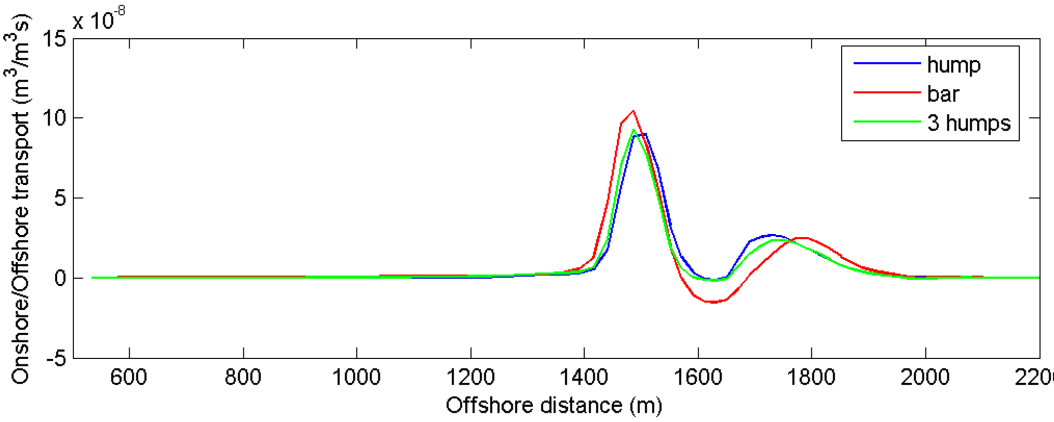


Figure 4-14 Net cross-shore transport, integrated over the length of the domain, per total amount of sand.

Figure 4-15 gives a clear idea of the cross-shore transport of sediment for the whole area. The large transports on the tips of the bar and the hump-crests are obvious and the rips are clearly visible as well. The cross-shore transports in the surf-zone seem negligible in comparison with the transport values on the nourishments. The transports reaching values of initially app. 2.10e^{-4} m^3/ms lead to high deformations of the nourishments during the first period after nourishing.

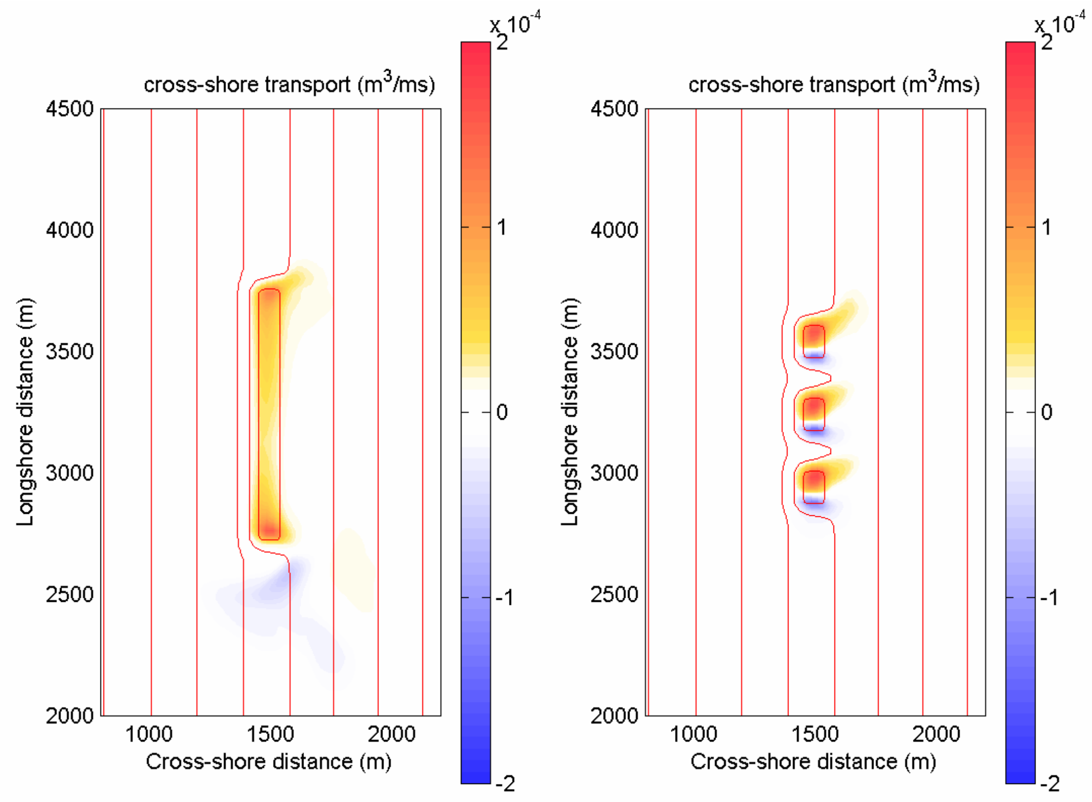


Figure 4-15 Cross-shore transport for the whole area, red colours are in onshore direction and blue is in offshore direction

Longshore

Longshore transport on the crests of the nourishments will lead to diffusion of the nourishments and distortion of the coast line. Diffusion of the nourishments will be large in the initial period when the bathymetry is far from the natural situation. From Figure 4-16 a number of conclusions and aspects for further investigation are summarized. For a complete overview of longshore transports, reference is made to Figure 4-17 in which the longshore transports are plotted for the overall area.

- The onshore effect is mainly visible in the lee zone of the nourishments. The waves are milder and generate a less strong longshore current resulting in less transport of sediments. Longshore transport is shifting shoreward as the waves are milder and break more onshore in the profile. At the transition from the bar-nourishment to the south and the north the longshore transports are changing as a result of the horizontal circulations at the tips of the bar. This is clearest from Figure 4-16, plot number three in which increasing (absolute) transports are shown at both sides.
- On the crest of the nourishments the longshore transports are distinct for both scenarios. For the bar nourishments upstream and downstream transports appear as for the hump scenario only downstream effects are there. This is the result of the set-up development as it was discussed before. For the single hump a higher longshore transport is visible on the crest of the nourishment as a result of higher velocities. Variation in the longshore length of the humps is expected to be the tool to optimise onshore transport (Chapter 5).

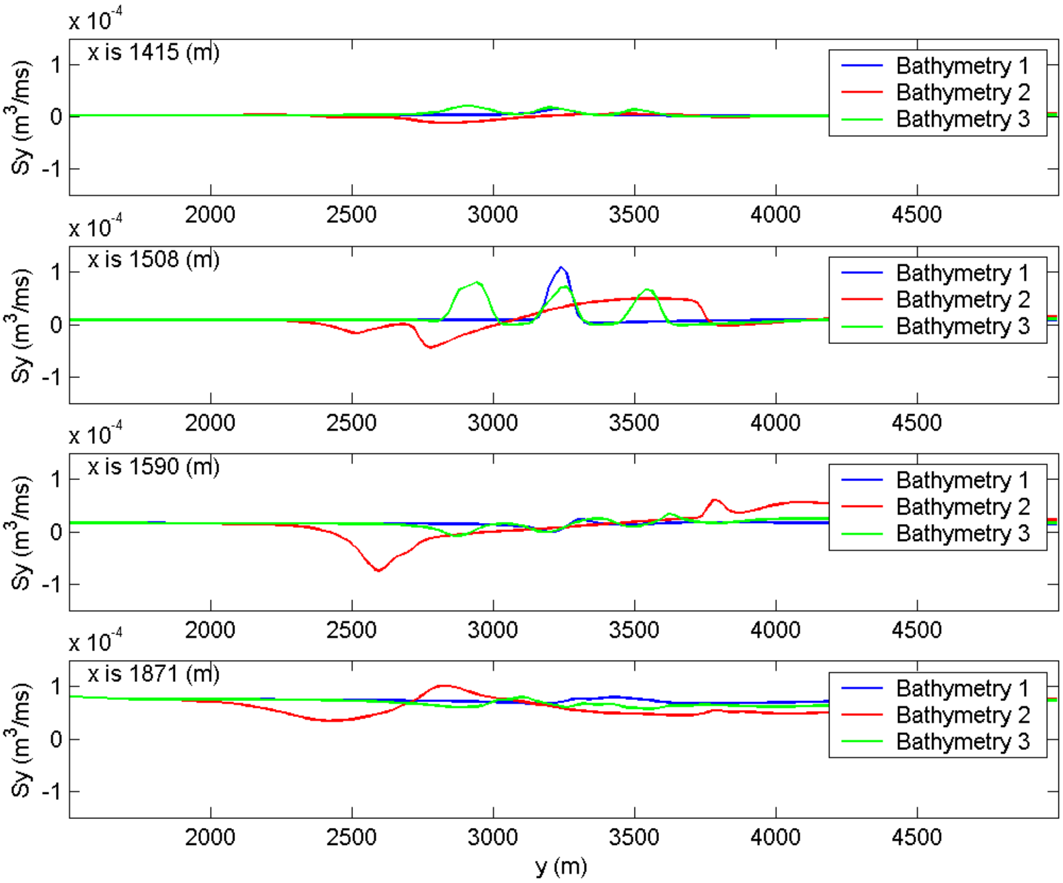


Figure 4-16 Longshore transports in m^3/s

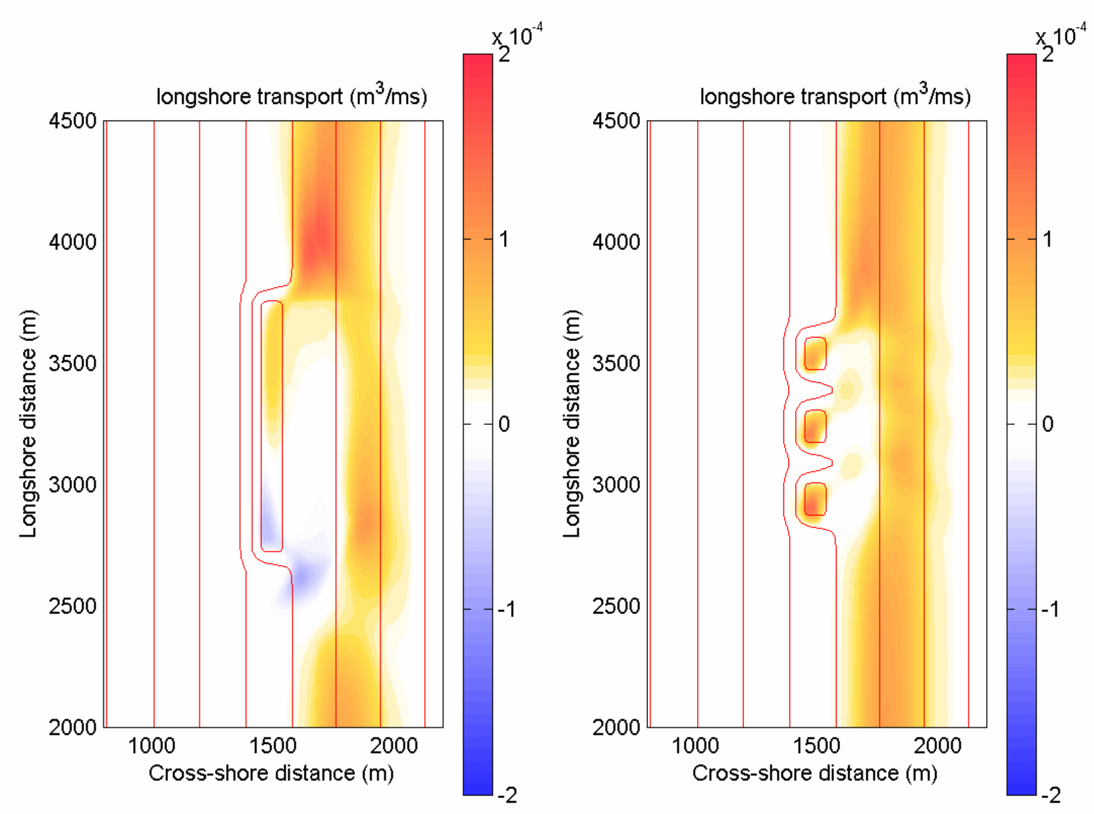


Figure 4-17 Longshore transports for overall area, red colours are positive and transport is directed from south to north. The blue colours denote the opposite, from north south.

4.2.5 Initial sedimentation and erosion of nourishments

Until now the transport-value magnitudes and directions have been analysed. The transport gradients describe the evolution of the area as a result of these transports, variations in transport have to lead to a loss or gain of sediment. In general the model area can be divided in sections for which a balance of transport can be determined. For every single section transport is described in two directions, longshore and cross-shore. And for both directions a net result for the individual section can be computed (see Figure 4-18). The summation of both values is the initial sedimentation/erosion rate for the concerning balance section.

In the figure it is shown that plot (a) is in balance, an equal amount of sand is going into the balance area as is going out. Plot (b) shows a balance area in which erosion occurs. The left boundary shows less input than the right boundary has output of sediment. This has to lead to a decrease of sediment for the area. For both the situations the cross-shore transport is in balance, leading to no sedimentation or erosion.

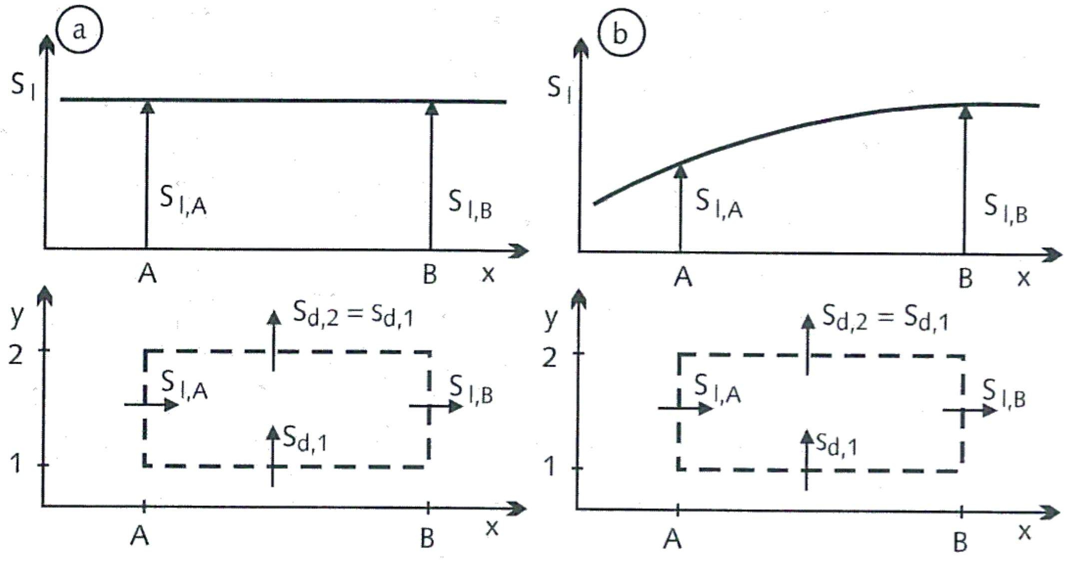


Figure 4-18 Transport balance for four random sections in the model area (TAW, 1995)

Figure 4-19 and Figure 4-20 show the initial sedimentation/erosion patterns for the whole area with the highest possible resolution for balance sections. The grid-cells used for hydrodynamic computation have been used for this. Because of the varying surface size off the grid cells the increase and decrease of volume of sediment per grid cell has been divided by the individual surface size of each grid cell to get a relative parameter. The same has been done for a situation without nourishments, the reference. For every scenario the reference situation had been subtracted from the sedimentation/erosion plot to obtain the autonomous initial behaviour. This leads to a value which describes the average velocity of bottom change in m/s in vertical direction.

From the figures it is clear that the largest initial change of bathymetry is at the nourished sections itself and just onshore of it. The change of the bathymetry in the surf zone is an order smaller. In cross-shore direction variations are only present at the crest of the nourishment. The effect causing the ‘boomerang’ shape is clearly visible for the bar nourishment, the tips are migrating significantly faster than the middle section of the bar. The circulations generated at the tips of the bar cause a clear longshore variation of the bottom. At the northern part it is mainly generating erosion, south the rip offshore causes transport and sedimentation and erosion. Overall it can be concluded that cross-shore variations are directly related with the nourishment, longshore variations are more or less due to hydrodynamic variations induced by the nourishment.

The longshore variations are hard to recognise as they are negligible in comparison with behaviour around the nourishments. In Chapter 5 (5.3) more attention will be paid to variations in the lee of the nourished sections. It shows that trapping of longshore sediments in the lee of the bar is somewhat larger than for the humps. Main conclusion is that accretion for the bar is more constant and will be much larger as an average in time when the nourished sections are exposed to varying conditions. The gaps in between the humps lead to disturbances in the surf zone which are highly dependent on varying conditions. Figure 4-19 and Figure 4-20 have been split into 3, the onshore effect, the longshore effect and the total effect. The order of magnitude of the transports for all plots is similar.

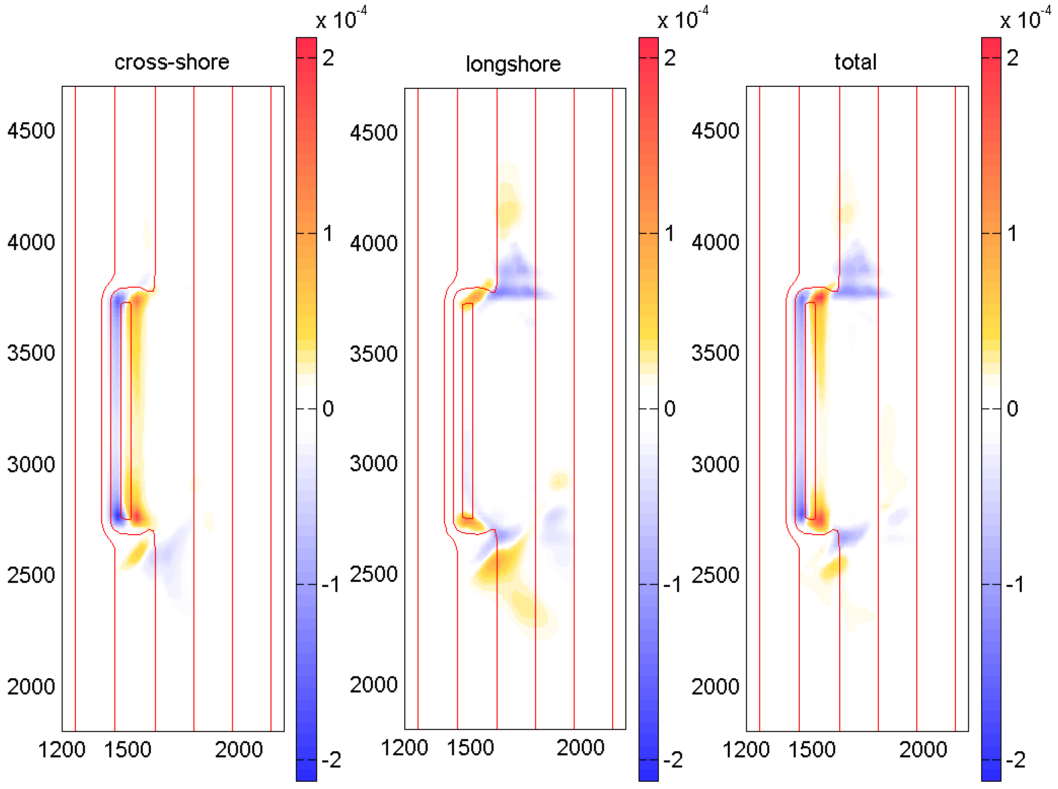


Figure 4-19 Initial sedimentation/erosion patterns in cross-shore and longshore direction and the summation of both (m/s) for elongated bar

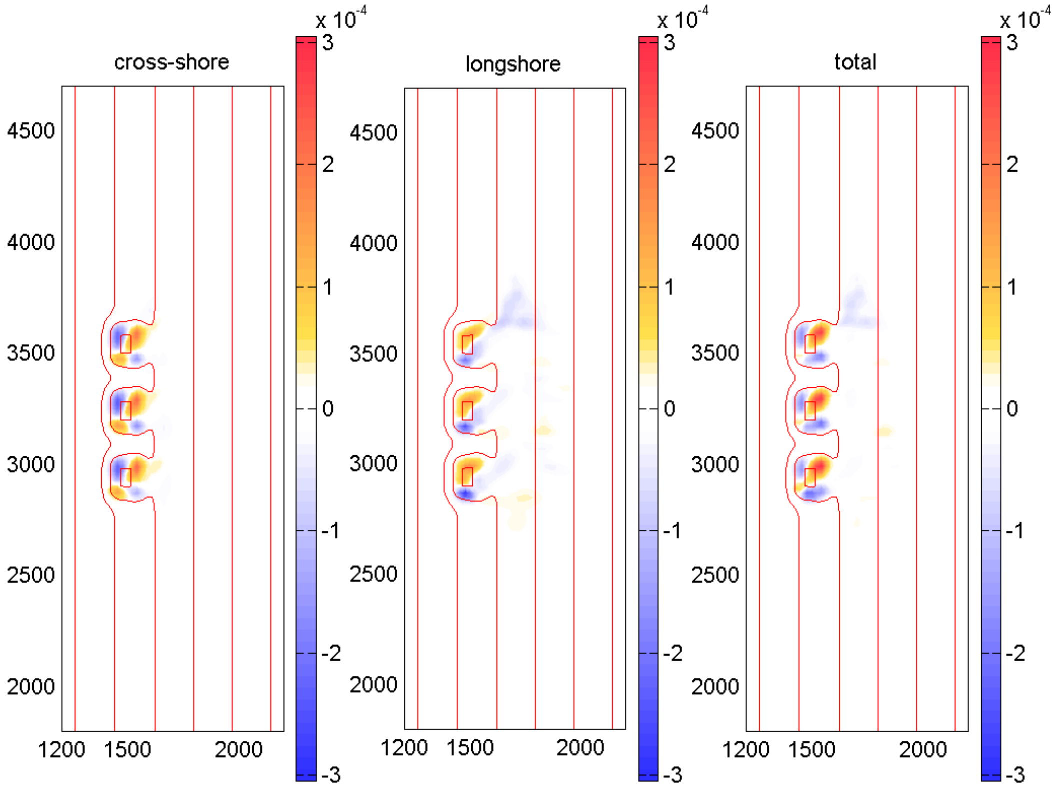


Figure 4-20 Initial sedimentation/erosion patterns in cross-shore and longshore direction and the summation of both (m/s) for 3 humps

4.3 Variation of hydrodynamic conditions

In general the morphological development of the shoreface is dependent on the hydrodynamic conditions it is exposed to. In the above only one condition has been analysed. Finally morphology will be determined by a summation of different conditions the nourishments are exposed to. Although this chapter is only describing the behaviour of sand and water in the initial situation, the picture will get more complete after comparing the different conditions and their properties like velocity, concentration and transport.

For the variation of the conditions distinction will be made between three categories, wave height, angle of incidence and waterdepth at the crest of the nourishment. The properties of the conditions are summarised in Table 4-4. For the significant wave height at deep water the wave period has been calculated by keeping the steepness of the waves at approximately 2,5 %. The bathymetries being analysed during this paragraph are the bar nourishment and the 3-humps nourishment.

Table 4-4 Variation of the conditions for further analysis, H_0 is the significant wave height at the seaward boundary, T is the matching wave period, θ the wave angle as it enters the wave grid and h_{cr} is the waterdepth at the crest of the nourishment

	H_0 (m)	T_p (s)	θ (deg.)	h_{cr} (m)
Condition 1	2	7	250	3
Condition 2a	1	5	250	3
Condition 2b	1,5	6	250	3
Condition 2c	2,5	8	250	3
Condition 2d	3	9	250	3
Condition 3a	2	7	240	3
Condition 3b	2	7	260	3
Condition 3c	2	7	270	3
Condition 4a	2	7	250	4
Condition 4b	2	7	250	5

The hydrodynamic properties, being the result of the different hydrodynamic conditions prescribed, will be dealt with less detailed than in the paragraph above. Only the aspects which are of interest for getting more insight in the behaviour of the nourishments will be described.

4.3.1 Variation of wave height

Wave height is the main wave property responsible for the morphological behaviour of the nourishments under investigation. The wave height determines the amount of energy being dissipated on the nourished section and thus the amount of sand brought into suspension and the development of currents transporting the sediments. The impact of the wave height will be much larger with high waves, though these conditions will occur less. The morphological impact of both severe and common waves will have their contribution to the migration of bars and humps. The chapter, in which the morphological development of the nourishments is dealt with, chapter 6, will give more attention to this aspect.

Appendices C-3 show the current as it develops for different wave impacts (H_s 1,5-2,5 meter). From the plots it will be clear that the cross-shore velocities do mostly vary in magnitude and not in direction or location. This is visualised in Figure 4-21; clear is that the velocity increases as the wave height increases till a certain level. In the upper two plots the velocities for the 2,5 and 3 meter wave heights are similar and even decreasing onshore in comparison with the 2 meter wave height. The stagnation of velocity increase is the effect of waves breaking more offshore of the nourishments and having their maximal height at the crest. This is even more clear for the different velocities for the 1,5 meter wave height (red line) and the 2 meter wave height (green), in the second plot the differences are significant. 80 meters more onshore the values are almost similar. Apparently the initial wave height difference does not have an effect on the cross-shore velocities anymore.

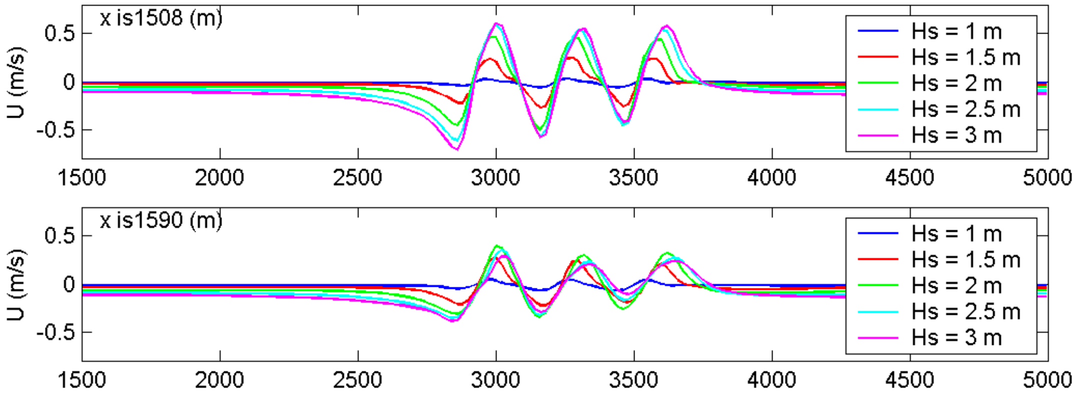


Figure 4-21 Cross-shore velocities for the humplike nourishment for different wave heights at different distances from the shoreline on the nourishment crest

More complicated is the current development in longshore direction. The higher the waves get the more offshore the longshore current reaches. From Figure 4-22 it can be seen that at the distance of the crest of the nourishments, in the undisturbed situation, a longshore current with a velocity of ca. 0,6 m/s is reached for a wave of 3 meter, in contrast with ca. 0,1 m/s for waves of 2 meters. In the vicinity of the nourishments the varying of the longshore velocities is similar as for the 2 m wave height as dealt with in the previous paragraph. The same trends are observed though the magnitudes of the variations grow with the wave height. Apparently the same effects of wave set-up and waterlevel variations occur, leading to sideward currents at the humps and bar. As the wave height is growing the longshore current is getting more dominant and as a result the longshore transport will have a large effect on sedimentation and erosion.

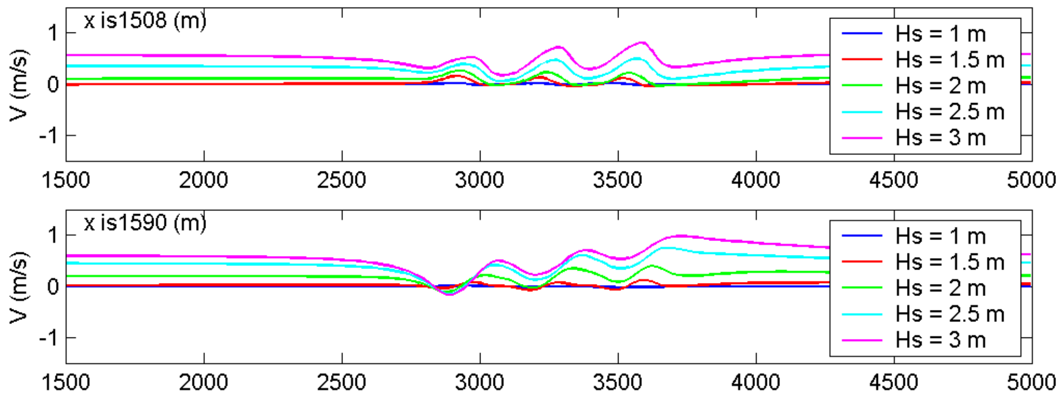


Figure 4-22 Longshore velocities for the humplike nourishment for different wave heights at different distances from the shoreline on the nourishment crest

The sedimentation erosion plots for the different wave heights and the 2 nourishing scenarios show that with high waves mainly in longshore direction large differences occur as a result of the set-up related currents. The initial sedimentation and erosion plots for the 2 scenarios and the different wave heights (1,5-2,5 m) are shown in the appendices C-4. Values of sedimentation and erosion reach to the order of magnitude of approximately 100 times the 1 meter wave height for the 2,5 m wave height.

As the waves get higher, the stronger the set-up related currents get and the larger the resulting transports are. The waterlevel increase on the crest for a wave height of 2,5 meter is up to 8 cm in comparison with the 3 cm for the 2 meter wave height. For a wave height of 2 meter the cross-shore transport was dominant and the effects of the nourishments are mainly onshore. For the case with the 2,5 meter wave height the longshore transport gets the overhand and the effects are mainly visible in vicinity of the bar-heads. The longshore current has large impact on the morphology of the nourishments. For the humplike-scenario the rips get much influence on the morphodynamics and the positive effect of the high set-up gradients leading to large onshore transports is turning into a negative effect as the rips are taking more and more sediment offshore. It seems that in the lee of the humps more accretion of sand is obtained and the longshore effect in the vicinity of the humps is less.

For the smaller waves the impact is less. For the 1,5 meter wave height, in contrast with the previous wave heights, the longshore transport is negligible and only impacts the bar heads. Overall the humplike nourishment contributes better to the shoreline. Optimal use is made of the positive effect of the set up gradients at the humps. From the appendix it is also seen that the shoreward effect increases for the lower waves as well. For the higher waves this nearshore sedimentation and erosion is there as well but it is negligible in comparison with the impact in the vicinity of the nourishments.

Figure 4-23 shows the cross-shore effect per longshore ray. Transport is plotted as a volume passing the longshore ray per second per nourished amount of sand. The dotted lines illustrate the 1000 meter bar, the solid lines the humplike nourishing. Clearly visible is that the effect varies per wave height as described above and that the cross-shore effect gets more positive for the humplike nourishment as the wave height is growing. It should be kept in mind that the plot only illustrates cross-shore transport and does not include longshore effects.

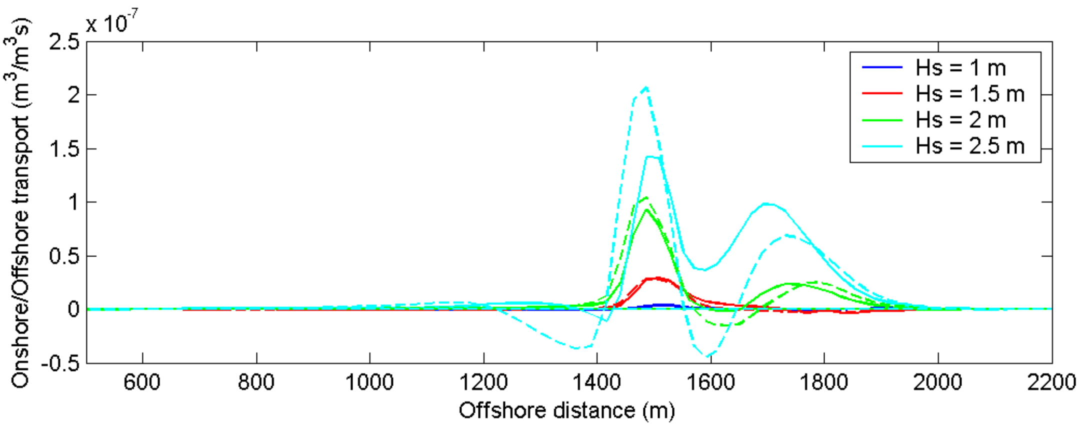


Figure 4-23 Total of cross-shore transports per wave height per nourished amount of sand, situation without a nourishment was subtracted (dots represent 1000 meter bar, solid line represents the humplike nourishment)

In Table 4-5 the cross-shore transport over the crest per nourished amount of sand is presented. The values only give a relative representation of reality. The actual processes and patterns in the nearshore zone are neglected in these figures. As can be concluded, the similarity between the two scenarios is large.

Table 4-5 Values for net transport for onshore area, all values times $10e^{-7}$ (m/m^3s)

	1 (m)	1,5 (m)	2 (m)	2,5 (m)
3 humps 100	0,03	0,28	0,72	0,85
1 bar 1000	0,03	0,26	0,75	0,77

4.3.2 Variation of wave angle

Variation of wave angle in the undisturbed situation leads to a variation in the wave-induced longshore current. In theory a wave angle of approximately 45^0 generates the largest longshore current. For this analysis the wave angle has been varied from 240 to 270 degrees, which is 60-90 degrees with the coast. For waves propagating normal to the coast no wave-induced longshore current arises in the breaker zone and a pattern of, what seems random circulations, dominates the breaker zone as every disturbance generates circulations.

In case of the nourishments an almost symmetrical pattern occurs; for the bar nourishment two identical rips arise, respectively north and south of the nourishment and for the humplike nourishment a complex system of circulations is generated. Applying other angles of incidence more gradual differences occur. In appendices C-5 the current development for the different wave angles and the 2 nourishment scenarios are shown.

In general it can be concluded that the smaller the angle with the normal, the larger the cross-shore velocities are and thus the larger the cross-shore transport is. This is illustrated in Figure 4-24 and Figure 4-25 in which it is clearly visible that the cross-shore velocities increase as the waves approach the coast more perpendicular. In Figure 4-25 you can see how the rip current at the southern part (y = 2700) moves further from the nourished bar as the waves enter under a smaller angle with the normal. In the latter situation (240 deg) the longshore current does not push the rip against the bar head. The smaller the angle of the waves with the shoreline, the larger the longshore current is and the larger the offshore component of the rip currents is. For the 270 deg wave angle the rip is not hindered by longshore currents and is flowing out more in longshore direction. In between the humps the rips are larger but have less influence in longshore direction, Figure 4-24. Rips have to escape through the gaps. More onshore the differences are clearly increasing as a result of the developing longshore current generated by waves breaking onshore of the humps. These are the waves passing the nourished humps.

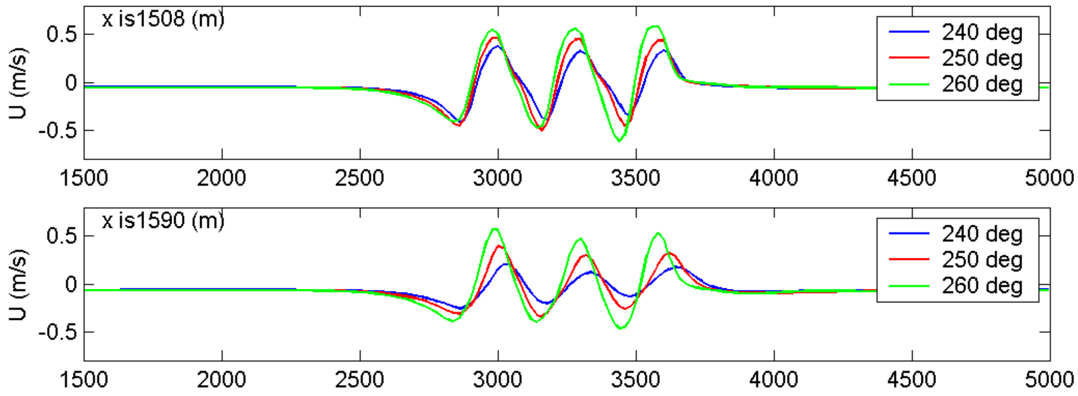


Figure 4-24 Cross-shore velocities for the humplike nourishment for different incident wave angles at different distances from the shoreline near to the nourishment crest

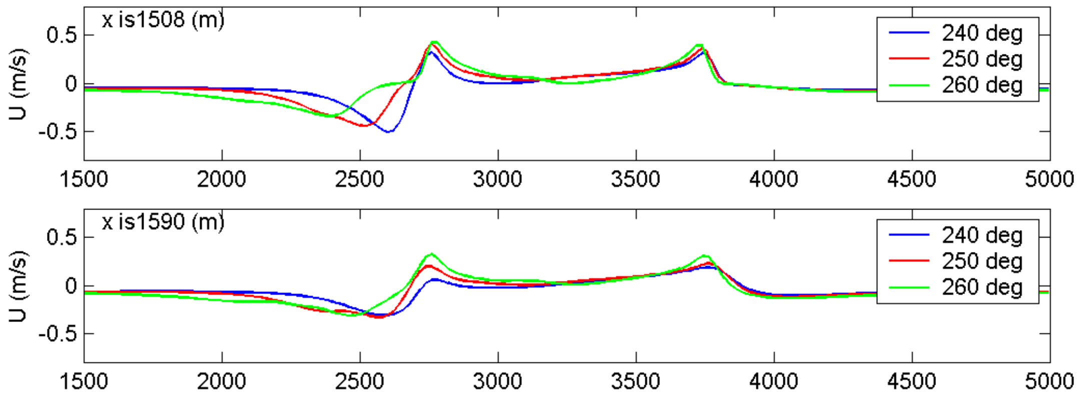


Figure 4-25 Cross-shore velocities for the bar-nourishment for different incident wave angles at different distances from the shoreline on the nourishment crest

Figure 4-26 indicates how the breaking of waves passing the humps has effect on the longshore velocities. A clear trend is visible at the onshore side of the crest. This effect will have influence on sedimentation erosion downstream of the humps.

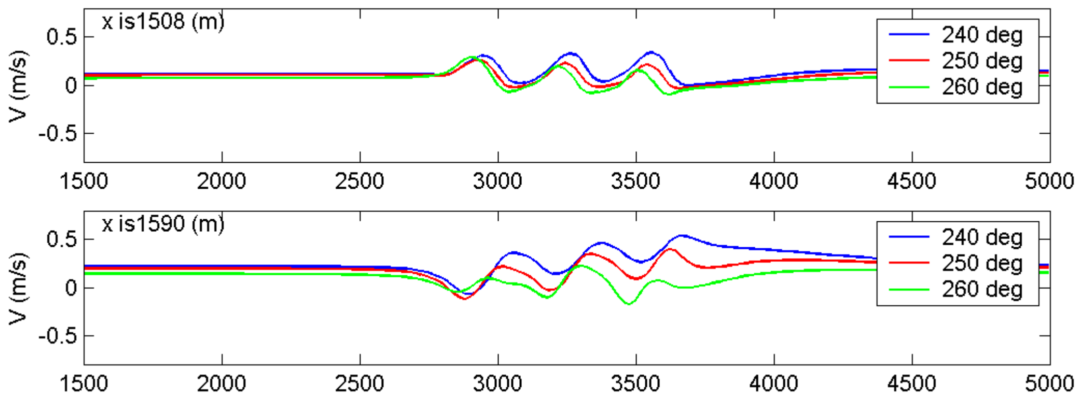


Figure 4-26 Cross-shore velocities for the humplike nourishment for different incident wave angles at different distances from the shoreline on the nourishment crest

In appendices C-6 the sedimentation erosion plots for the wave angle variation are shown for the two scenarios. Overall it is clear that the cross-shore effect is increasing as the waves are propagating more perpendicular to the coast. Especially for the humplike scenario this result is remarkable. In the plots of appendices C-6 it is seen that the nearshore effect is getting larger as the wave angles decreases (240 deg). This effect is caused by the shadow effect of the waves and has trapping of sand as a result.

Figure 4-27 and Table 4-6 show the variation for the overall cross-shore effect of the different incident wave angles for the two bathymetries. Again the cross-shore transports were integrated over the longshore length of the modelled area. The transport is represented as volume sand passing per longshore ray per initial second per nourished amount of sand. In the figure it is clear that for waves entering perpendicular a much more positive result is obtained. The differences at the crest of the humps vary significantly in contrast with those for the bar. Apparently the angle of incidence of waves is of great importance in case of hump nourishing. This effect is expected to be larger as the gap in between the humps is larger and the current in between can better develop. This will be dealt with in the chapter following.

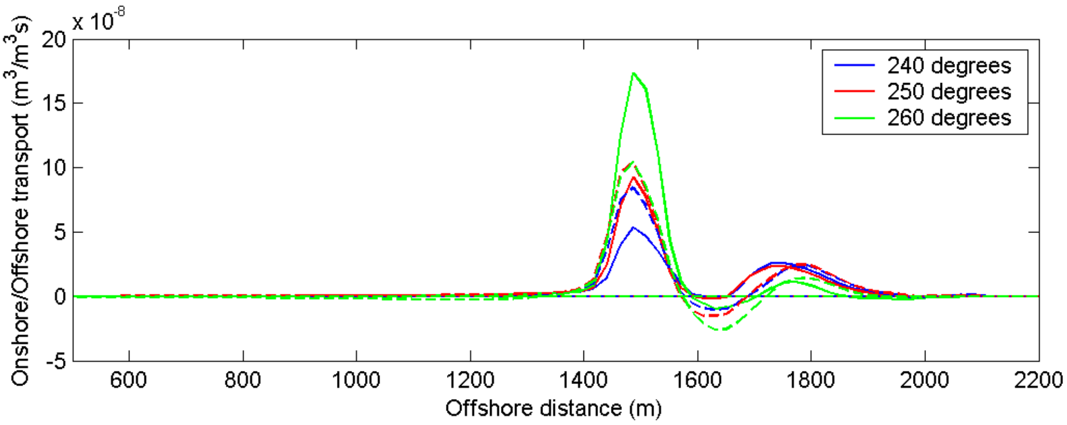


Figure 4-27 Total of cross-shore transports per wave angle per nourished amount of sand, situation without a nourishment was subtracted (dots represent 1000 meter bar, solid line represents the humplike nourishment)

Table 4-6 Values for net transport for onshore area, all values times 10e^{-7} (m/m^{3}s)

	240 deg.	**250 deg.**	**260 deg.**
3 humps 100	0,46	0,76	1,59
1 bar 1000	0,70	0,82	0,85

Conclusion of wave angle variation is that especially the effect on sedimentation and erosion is large for the humplike nourishing. In case of waves propagating almost perpendicular (260 deg) the contribution is most positive and significantly higher than for waves with a larger angle of incidence (240 deg). A difference of 10 degrees leads to onshore transports which are more than double. This is in contrast with the bar nourishing for which the effect is only ca. 7 % after varying the angle with 10 degrees. For the bar nourishing transport is clearly more constant as the incident angle is varying.

4.3.3 Variation of waterdepth

For practical reasons shoreface nourishments are in general only being executed on a waterdepth of 5 meters and more. The dissipation of energy on the nourished section is the main cause of sediment transport in onshore direction. This makes that the waterdepth is of large influence on the behaviour of the nourishments. In this study the depth has been chosen to be 3 meter for initial computations. Differences will be more clear and comparable with severe storm conditions. In reality it is seen that these severe storms are the cause of the characteristic behaviour described before. This paragraph deals with different waterdepth and gives insight in the different behaviour of the nourishments. Apart from the 3 meter depth the two main nourishment scenarios are implemented at depths of 4 and 5 meter as well, these depths are measured at the crest of the nourishment. The nourishment itself stays constant and has a crest height of 3 meter above the local bottom.

Variation of waterdepth has its main influence on the breaking of waves. For deeper water waves break more offshore and the waterlevel variations at the nourishments will be significantly less. In the previous paragraphs it was described how wave energy dissipation leads to larger onshore velocities at the tips of the bar and the humps. Figure 4-28 and Figure 4-29 show the cross-shore velocities at the crest of the nourishment. Clearly visible is how the velocities at the bar-heads decrease for the deeper water and how the positive effect will be smaller at deeper water.

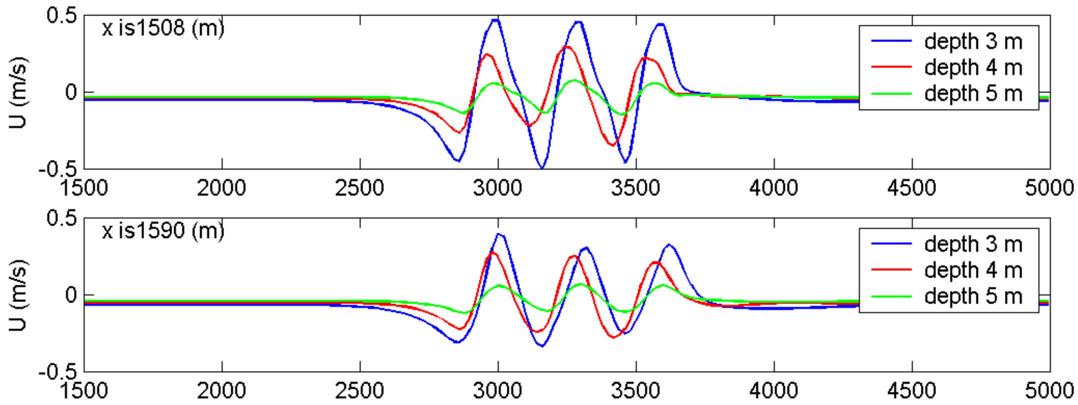


Figure 4-28 Cross-shore velocities for the bar-nourishment for different waterdepth at different distances from the shoreline on the nourishment crest

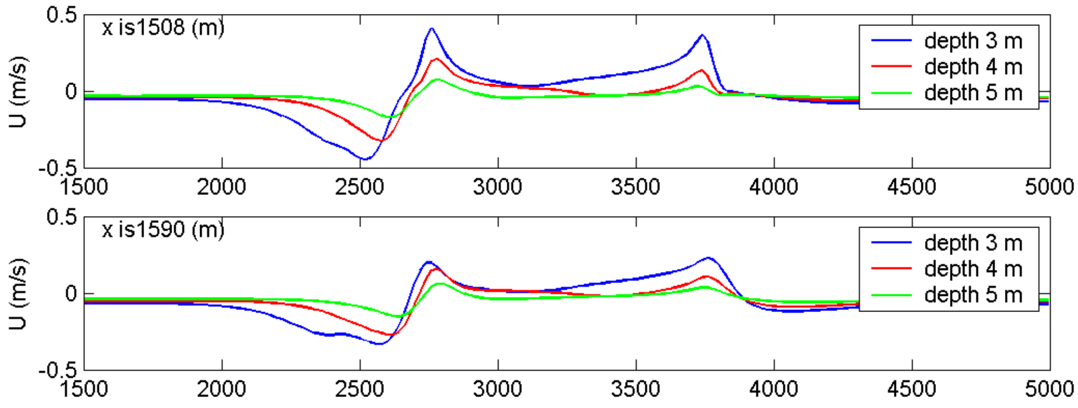


Figure 4-29 Cross-shore velocities for the bar-nourishment for different water depth at different distances from the shoreline on the nourishment crest

For the humplike nourishing it is clear how the rip current grows and is pushed against the downstream hump as the waterdepth is decreasing. The stronger rip current has as a result that more sediment is transported offshore leading to a less efficient system. A larger gap between the nourished humps is expected to reduce this offshore transport. Figure 4-30 shows the in longshore integrated cross-shore velocities for the different water depths. The dots represent the 1000 meter bar, the lines the humps. Conclusions from these plots are:

- For large water depths, like 5 meter, the differences in cross-shore transport are negligible at the crests. Apparently wave dissipation does not have the positive effect here as it has for smaller depths. The waterlevel does not increase significantly and variations do not lead to differences between humplike and bar-nourishing;
- For the 5 meter waterdepth no accretion is shown nearshore. Apparently the trapping of sand does not occur for this water depth. The nearshore zone does show disturbances as a result of the bar heads and the resulting cross-shore effect on the nearshore.
- The shallower the nourished sections are, the more onshore transport is resulting and the larger the difference between the humplike and bar-nourishing is. Hump nourishing is in this case the more positive method;
- In green the result for the 3-meter depth is illustrated, clear is that the result for humplike nourishing, in comparison with the bar-nourishing, decreased again. This effect is due to the rip current and can be compensated by increasing the mutual distance between the humps.

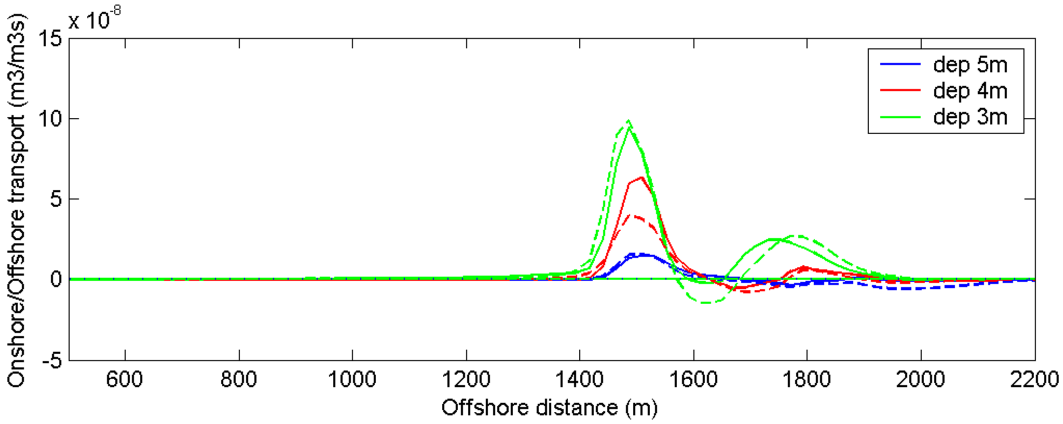


Figure 4-30 Total of cross-shore transports per wave angle per nourished amount of sand, situation without a nourishment was subtracted (dots represent 1000 meter bar, solid line represents the humplike nourishment)

Remarkable is the result for the 4 meter water depth. In contrast with the other results, the humps are much more positive for this situation. Analysing the velocity patterns around the humps shows that the rips behave differently from the rips in all the other situations. The rip currents show a strong varying effect in time, velocities vary both in magnitude as in location (see Figure 4-31). As the water level and the wave properties are stable the phenomenon has to be a result of vortex dynamics responding slowly on the system. Chapter 5 will show the dependency of the gap width of the humps in combination with this meandering effect.

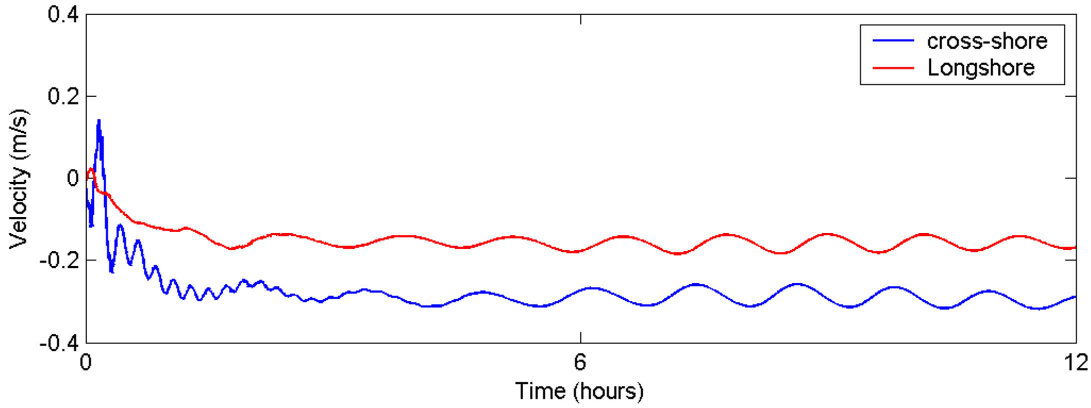


Figure 4-31 Variations in rip currents in between humps for water depth of 4 meter

Table 4-7 shows the values for the averaged, initial change due to sedimentation and erosion for the whole onshore section. In appendices C-7 a more detailed analysis of the initial sedimentation erosion for the whole area is presented.

Table 4-7 Values for net transport for onshore area, all values times 10e^{-7} (m/m^{3}s)

		3 m	**4 m**	**5 m**
3 humps 100	Total	0,72	0,59	0,14
1 bar 1000	Total	0,75	0,38	0,17

4.4 Synthesis

The previous chapter shows how wave dissipation has its effect on hydrodynamics around nourished humps and bars and how the hydrodynamics subsequently react on sediment transport. In general wave energy dissipation is resulting in a water level set-up. This waterlevel set-up can not be balanced over the whole length of the bar and not at all for the humplike nourishments. This lack of balance in water level leads to an increased mass-flux of water at the tips of the bar and at the crest of the humps causing higher transport of sediments here. This effect causes the “boomerang shape” nourished bars form after some time.

The increased mass-flux at the tips of the bar and the humps leads to a concentrated current leading to complex circulations onshore. Conflicting currents originating from up- and downstream humps and the wave induced longshore current in the breaker zone steer the nourishment induced currents offshore. These so called rip currents have negative effect as they transport sediments offshore and cause difficulties for recreation. As the rip currents flow offshore at deeper water, where sediment concentrations are low, the overall effect is positive.

Overall the humplike nourishing shows advantage in comparison with the bar nourishing. Per amount of nourished sand the cross-shore effect on the crest is similar for the analysed cases, expectation is that by varying gap width and hump length efficiency can even increase. More onshore of the nourished sections the humplike nourishing shows even more advantage. The humplike nourishment generates less intense currents onshore and as a result less impact is seen here due to offshore transports.

The onshore effect of sediment trapping showed advantage in the case of the nourished bar. In the lee of the bar, waves are calmer resulting in a weaker longshore transport and thus accretion. Near the tips of the bar large disturbances occur as a result of the rips. Varying wave conditions are expected to spread this effect and finally lead to accretion in the lee and some minor erosion just sideward of it. For the humps a similar effect was seen, though penetration of waves in between the humps causes disturbances here. Erosion spots are alternating sedimentation spots which will also be averaged over the lee of the humps in time.

The nearshore effect of the nourished sections was not analysed in a quantitative sense. Still the conclusion can be made that humplike nourishing has less direct impact on the shoreline as a result of trapping of sand. Chapter 6 will give some more attention to this. Cross-shore effects are far more dominant for the analysed conditions and showed advantage for the humplike scenarios. It should be considered that the presented analysis only presents initial sedimentation and erosion.

The higher the waves are, the larger the differences between the scenarios. This can be explained by the effect that waves dissipate more energy at the nourished sections as they get higher. At the crest the onshore transport is largest for the bar nourishing, this effect is compensated by the effects onshore of the nourishment. Overall the contribution of higher waves within a wave climate will make the difference for the efficiency of the nourishing method. A morphodynamic study with exposure to a more realistic wave climate averaged over a year will give more insight.

The same can be said for variation of water depths. The shallower the crest of the nourishments lays, the higher the influence of the described processes. For the different scenarios a water depth of 3 meters on top of the crest was analysed. This showed the occurring differences well and the results give insight in the behaviour. In reality these will only be a small contribution on the overall behaviour of the nourished scenarios. The next chapters will take a waterdepth of 4 meters as average on the crest. This will give more realistic results.

The angle of incidence of waves has a large influence on the sedimentation and erosion both on the nourishments as in the lee of it. It was shown that the more perpendicular the waves approach the coast, the higher the cross-shore effect. Especially for the humplike nourishment this effect is remarkable. Obviously the longshore flow due to wave breaking in between the humps has a large influence on this cross-shore transport. The trapping of sand is mainly determined by the more parallel approaching waves. They cause the larger longshore current and thus a larger disturbance leading to accretion. Variation of angles is expected to lead to more gradual behaviour nearshore and more accretion in case of the bar nourishing.

5 Geometric variation and optimisation of humplike nourishments

5.1 Introduction

In the previous chapter an extensive analysis was done on the hydrodynamic behaviour of shoreface humps and bars. Concluded was that the implementation of humplike nourishments showed advantage in comparison with the conventional method and that the method can be more efficient in potential. This chapter goes further into the behaviour of humplike nourishments and will deal with different nourishment scenarios. Objective of this chapter is to learn how the efficiency of humplike nourishments depends on the individual lengths of the humps and their mutual distance.

A number of scenarios are being analysed, for 5 different hump lengths (50-400 meter) and gap widths varying from 200 to 500 meter the properties will be compared. The minimal distance of 200 meter is chosen so the humps do not have overlap at the bottom as a result of the sloping ends. The overall goal is to check whether it is possible to optimize the use of humps as shoreface nourishments and what are the determinative variations.

Table 5-1 Shoreface nourishment scenarios for analysing of hump geometries

	Number of nourishments	Length of crest (m)	Mutual Distance (m)
Bathymetry 2	1	1000	-
Bathymetry 3	3	100	200-500
Bathymetry 4	3	50	100-500
Bathymetry 5	3	200	200-500
Bathymetry 6	3	300	200-500
Bathymetry 7	2	300	200-500
Bathymetry 8	2	400	200-500

In chapter 4 analyses was executed on the variability of nourishment behaviour as a result of different hydrodynamic conditions. In this chapter the reference condition (H_s = 2, approach angle = 250 deg. and T_p = 7 sec.) will be used again. Results showed that the waterdepth has a large effect on the behaviour and wave induced circulations behave different at various depths. Because the implementation depth will be at a minimum of 5 meters below average waterlevel a depth of 4 meter will be analysed as reference. 5 meter water depth did not result in distinct variations in the previous analysis and will not contribute to the expected efficiency. Tidal range in the actual situation will cause variations of the water level; a depth of 4 meter will be reasonable and determine the behaviour for a certain period of time.

The following paragraphs will first deal with the variance of hydrodynamics around the nourished humps and the resulting cross-shore transport as a result of these nourishments. The dependency of length and gap width and the bandwidth for optimisation will be discussed hereafter. In the last part the nearshore variations in transport and initial morphology are analysed. Finally this chapter will give insight in the design of shoreface nourishments in the form of humplike nourishments.

5.2 Variations of humplike nourishments and influence on its cross-shore behaviour

5.2.1 Hump length variation

In Figure 5-1 the total transports for four different nourishment scenarios are illustrated in blue vectors. The nourishments all have a mutual distance of 200 meter, the hump lengths vary from 100 meter in the left plot to 400 meter in the most right plot. Together with the different nourishment scenarios the transports, as a result of the bar nourishment, are described by red vectors. For the 400 meter hump lengths only 2 humps are modelled in order to keep the amount of nourished sand similar to the conventional method and keep the modelled area small. In this way nourishment scenarios fit into the computational grid. The 300 meter hump length is being executed for both the 2- and 3-humps variants to see what impact this has.

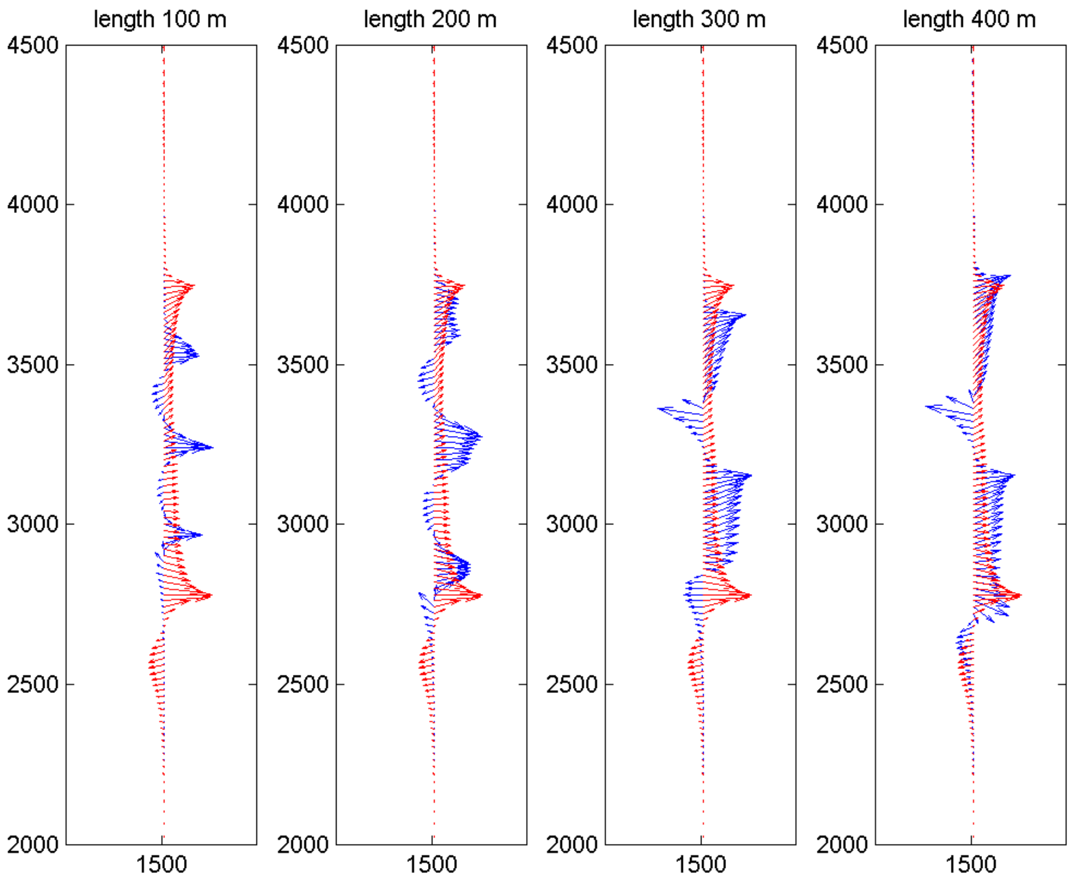


Figure 5-1 Total transports (m^3/ms) on the crest of the nourished scenarios, red represents the bar nourishment, blue the four different hump lengths all with a mutual difference of 200 meter.

In the figure a clear difference between the scenarios is visible. For the small hump-lengths the transports on the individual humps show similar patterns. This is in contrast with the scenarios with lengths of 300 and 400 meter. In these cases the south and northern humps show clear differences. In all cases, except for the one with 100 meter humps, the most upstream humps shows more intense onshore transport than the northern, downstream humps.

In Figure 5-2 it is seen how smaller humps lead to different cross-shore velocities, onshore velocities on the 100 and 200 meter humps are clearly more peaked than for the 300 and 400 meter humps. For the longer hump lengths the rip current in between is getting significant larger. This is most clear for the scenarios with humps of 300 and 400 meter. The effect of the onshore velocities being larger at the tips is seen for the 400 meter hump. This is even clearer for the transports, Figure 5-3. Apparently a 400 meter hump starts behaving like a bar and has a better developed set-up at the crest leading to parallel currents.

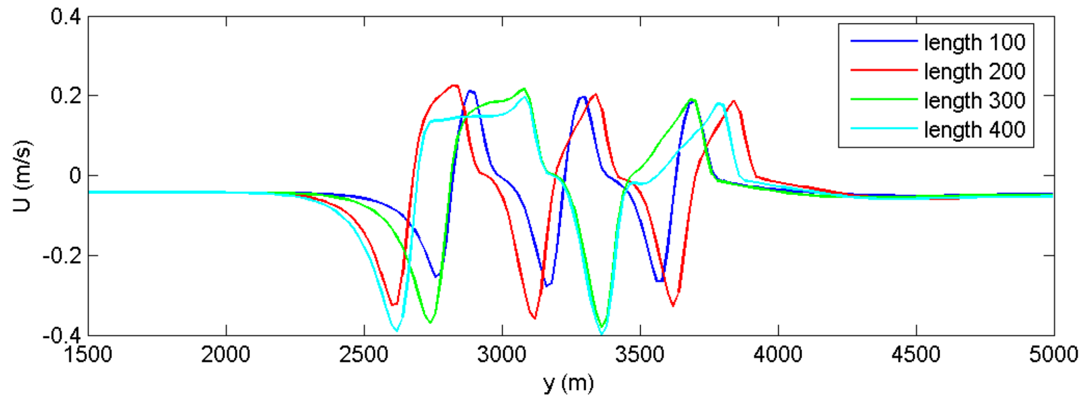


Figure 5-2 Cross-shore velocities for the different hump lengths and a gap width of 200 meter on the crest of the nourishments, positive is in onshore direction, negative in offshore direction

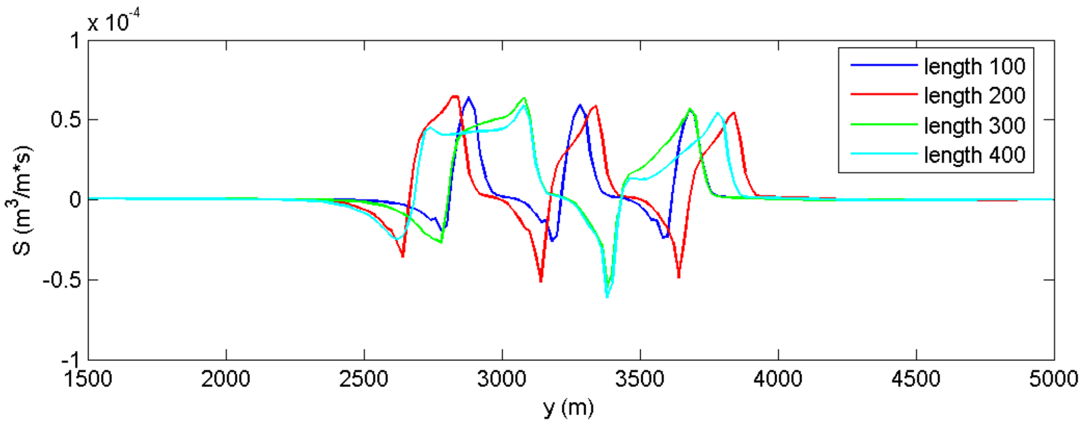


Figure 5-3 Cross-shore transports for the different hump lengths and a gap width of 200 meter on the crest of the nourishments, positive is in onshore direction, negative in offshore direction

Another effect which was mentioned before was the large differences the humps showed per scenario. These differences seem to grow as the length of the humps grows. For the upstream hump the onshore pattern for the 400 meter hump is similar to the 1000 meter bar. The tips show larger onshore transport while the middle section has a smaller almost constant onshore transport. This pattern is expected to develop as the hump gets larger. In contrast with this the downstream hump shows less resemblance. The downstream tip of this hump shows similar transports as the bar situation, the southern tip shows no onshore transport at all. This is due to a combination of the rip current flowing offshore and the opposing longshore current as a result of the waterlevel gradients. When executing more humps on a row the efficiency will be highest when using a smaller hump length. The onshore transport per nourished length will be higher and the transport patterns per individual hump will be more similar and humps will migrate onshore more equally. For the 300 meter humps, scenarios with 2 humps and with 3 humps are modelled to see what the effect of the latter described effect is. For these cases it is indeed seen that the third hump behaves like the second hump with both 2-hump and 3-hump scenarios. The larger the number of humps is, the smaller the efficiency will get. Appendix D-1 shows both scenarios in more detail in combination with the bar nourishing, the effect is clearly visible.

5.2.2 Gap width variation

Variation of gap width has only a small effect on the total cross-shore transport on the crest of the nourishments. Figure 5-4 and Figure 5-5 show the behaviour of transport on the crest of the humps for scenarios with 100 and 400 meter hump lengths.

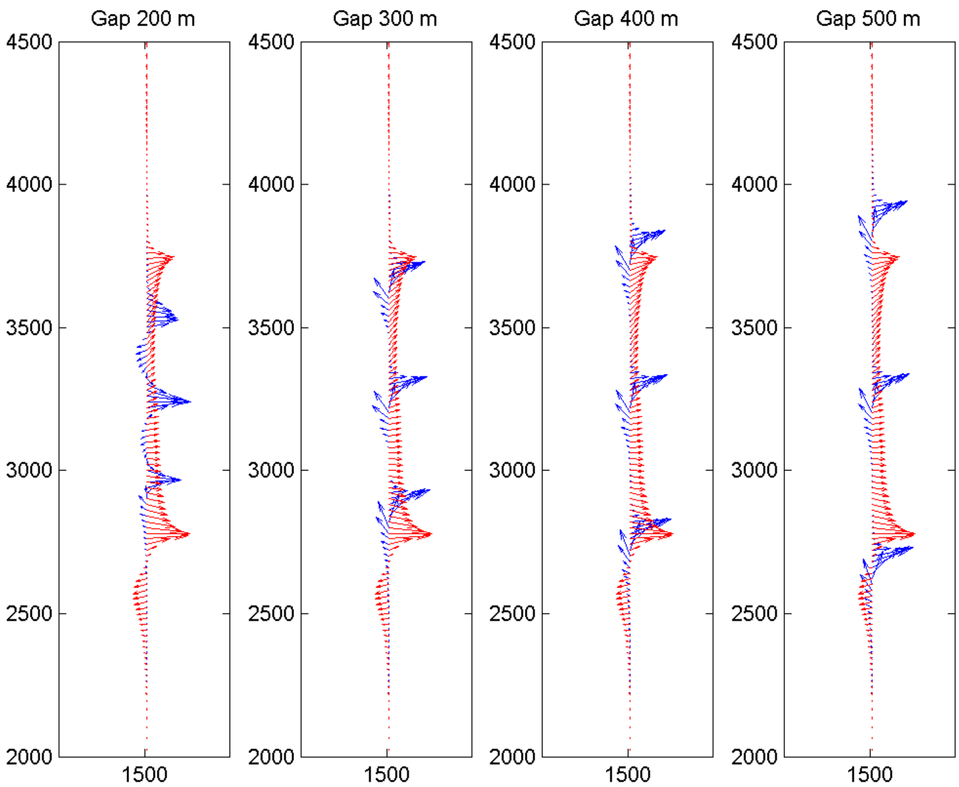


Figure 5-4 Total transports (m^3/ms) on the crest of the nourished scenarios, red represents the bar nourishment, in blue different gap widths for 3 humps with a length of 100 meter.

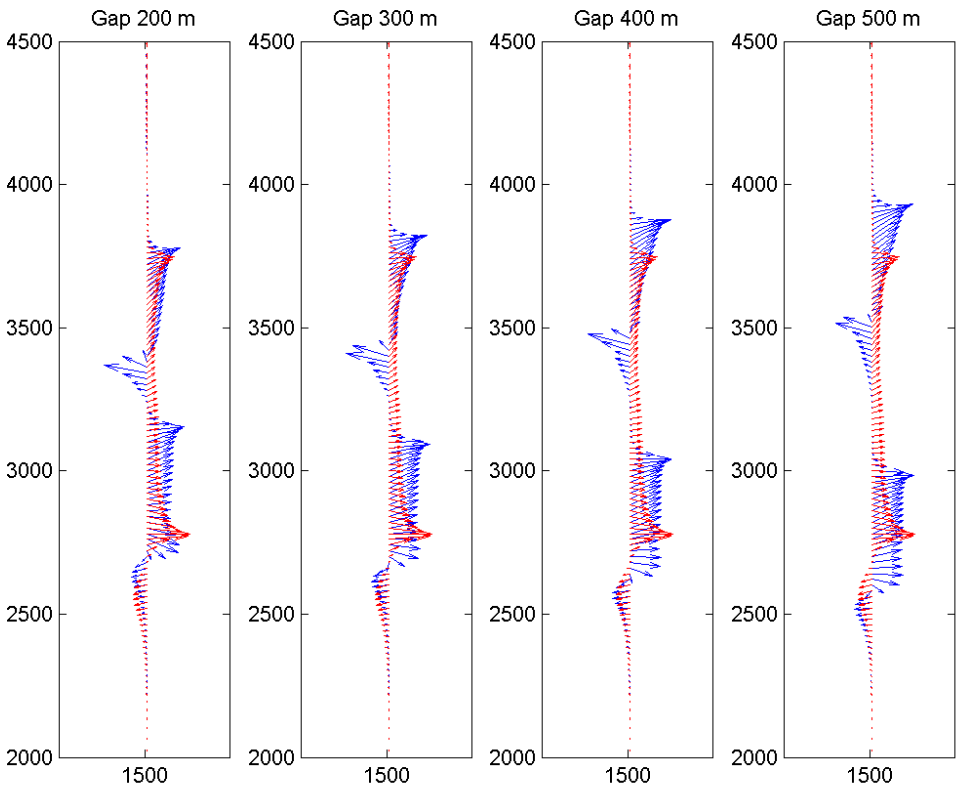


Figure 5-5 Total transports (m^3/ms) on the crest of the nourished scenarios, red represents the bar nourishment, in blue different gap widths for 2 humps with a length of 400 meter.

In general it is concluded that the gap width does not have large influence on the cross-shore transport as it is illustrated by the previous figures. The rip currents in between the humps are still attached to the downstream humps and have their effect on this hump on cross-shore transport. Apparently the rip is not a result of water which has to flow offshore as fast as possible but is caused by conflicting currents. This effect was already seen for varying approach angles of waves. For humps with a length of 100 meter a clear difference is present between the 200 meter gap width and the larger widths. For the 200 meter gap width another effect occurs, which has been dealt with in chapter 4 (the varying of depth).

Figure 5-6 shows the transport values for the humps with a length of 400 meter on the crest of the nourished sections. Remarkable is that the onshore transport patterns do not seem to vary in magnitude. The offshore transports decrease as the gap width is getting larger. This figure illustrates that the overall onshore transport may be a little bit larger for large gap widths but that the total nourished length is much larger and the efficiency is small in this way. Wide gaps will lead to larger variations in the nearshore zone as well; this might hinder the positive effect of sediment trapping. This will be dealt with later in this chapter.

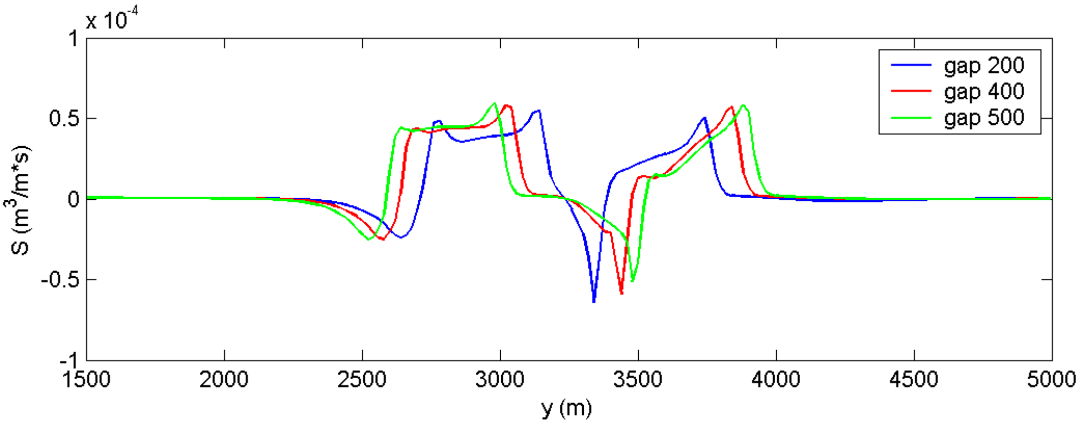


Figure 5-6 Cross-shore transports for the different gap widths and a hump length of 200 meter on the crest of the nourishments, positive is in onshore direction, negative in offshore direction

5.2.3 Optimisation of hump-length and mutual distances

Gap width and hump length both have influence on the morphodynamic behaviour of shoreface humps. By variation of these properties and evaluating them, the optimum scenario for shoreface humps can be determined. As chapter 4 already discussed, humplike nourishing has advantages in comparison with bar nourishing. In the previous subparagraphs a number of scenarios were analysed, from these it was concluded that mainly the hump length leads to differences in cross-shore transport.

Evaluating nourishment scenarios has as difficulty that a number of aspects can be seen as important for the efficiency of the scenarios. As this section will show, it is impossible to bring back all parameters to one value and evaluate this number as it is. Aspects of interest when evaluating the scenarios are the following.

- Total transport of sediment onshore as a direct result of the nourishing. This sand is a direct contribution to the nearshore zone. Objective of nourishments will be to add a certain amount of sediments to the coastal profile and widen the beach;
- The ratio between the nourished amount of sand and the onshore effect of the scenarios, a high onshore transport as a result of a scenario for which only a small amount of sand was needed will be evaluated as a good scenario;
- The total length of the nourished section, a large gap width can lead to higher onshore transport but the efficiency decreases as the total stretch of utilized coast is increasing.

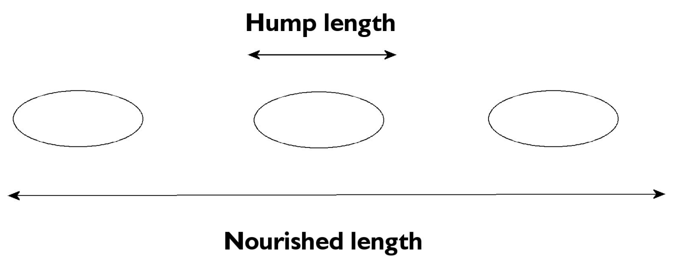


Figure 5-7 Nourished length in comparison with hump length

Not only is the onshore effect of the nourishments themselves contributing to the sand balance. Trapping of sand in the lee zone of the nourished sections can be one of the intended effects as well. Policy makers decide whether a nourishment design has to fulfil this objective. The disadvantage of this trapping of sand is that erosion will occur more downstream. This study more or less leaves lee zone processes out of its scope. Objective is to gain as much sand onshore as a result of the nourishments itself. The paragraph hereafter will deal with this aspect.

The main three parameters for the evaluating are the onshore transport, the amount of nourished sand and the length of the nourished area. These parameters will be evaluated in combination with the design parameters, the gap width and the hump length. Table 5-2 shows the amount of sand needed per scenario.

Table 5-2 Amount of nourished sand per nourishing scenario

Length	**Number**	**Sand volume (m^3)**
1000	1	510.000
50	3	210.000
100	3	270.000
200	3	420.000
300	3	560.000
300	2	370.000
400	2	470.000

Efficiency to amount of nourished sand of the different scenarios

Figure 5-8 covers all different scenarios into one single plot:

- Hump length on the horizontal axes, per length different scenarios were executed. These different values per hump length represent:
- Gap width which is distinguished by the various colours in the legend of the figures;
- Scenarios with 2 humps and 3 humps are distinguished by respectively ‘o’ and ‘+’. For the 300 meter hump lengths both scenarios are represented;
- The vertical ax shows the efficiency parameter, this can be transport in m^3/s, relative transport per nourished amount of sand (%) and relative to the nourished length (1/m). Division by the conventional bar nourishing a dimensionless parameter is obtained;
- The black dotted line represents the efficiency value for the reference bar.

Figure 5-8 shows that the amount of onshore transport increases as the hump lengths increase and thus the amount of nourished sand increases. There is a linear trend visible for the 3-hump variants (‘o’). The red circles for the 100 and 200 meter variants show less coherence. These are the values discussed before and are the result of the meandering rips. As it was concluded before these rips result in larger onshore transports as they have less contact with the humps and thus less offshore transport. For a certain number of scenarios the overall onshore transport is larger than for the bar nourishing. Apparently longer humps result in a larger onshore transport, though it is assumed that an optimum is obtained for a certain length and onshore transport will decrease to a constant value comparable to that of the black dotted line. Morphodynamic analysis of the different scenarios shows this optimum in chapter 6.

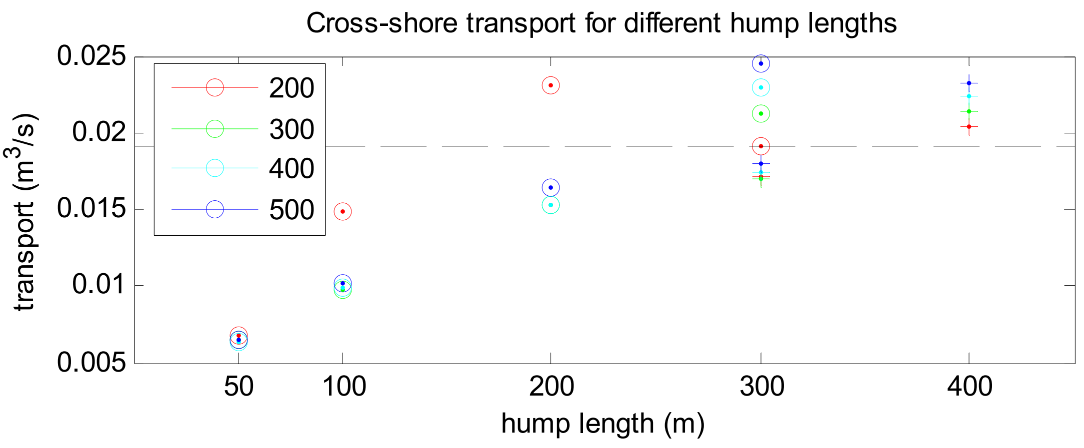


Figure 5-8 Transport onshore per nourished scenario, horizontal axes presents hump length, colours distinguish gap widths, circles are scenarios with 3 humps nourished and plusses represent the 2 humps scenarios

The true efficiency of the different scenarios is not only dependent on the amount of sand transported onshore but on the nourished amount of sand as well. The larger the relative amount of sand going onshore is, the larger the efficiency is. Figure 5-9 shows the relative transport onshore. These values are obtained by:

$$\frac{Transport\ onshore}{Nourished\ amount\ of\ sand} \cdot \frac{m^3/s}{m^3} = m^3/m^3 s \qquad \text{5-1}$$

- Values are divided by the value for the conventional bar nourishing so a relative value is obtained. For example a scenario with a hump length of 300 meter and gap widths of 500 meter is approximately 20 % more efficient than the
- The red circles for 100 and 200 meter humps are left out of the scope of the present analysis. The values show behaviour which is not expected to be representative for the morphodynamic behaviour;
- Apparently the efficiency is increasing as the hump lengths increase, however this increase is clearly not linear. In case of the 3-hump scenarios ('o') a maximum efficiency is reached for a length of 300 meters. For the small humps the contribution of the side slopes on the nourished volume is large. These slopes have less impact on wave breaking and therefore efficiency increases as the humps get longer;
- As the hump lengths grow the influence of the gap width is increasing as well. This is explained by the effect of the increasing currents generated on the humps leading to more rip strength. Apparently 300 meter hump lengths, in contrast with 200 meter, generate shore-parallel currents;
- Scenarios with 2 humps are clearly more efficient than with 3 humps. This effect is explained by the contribution of the upstream hump being larger;

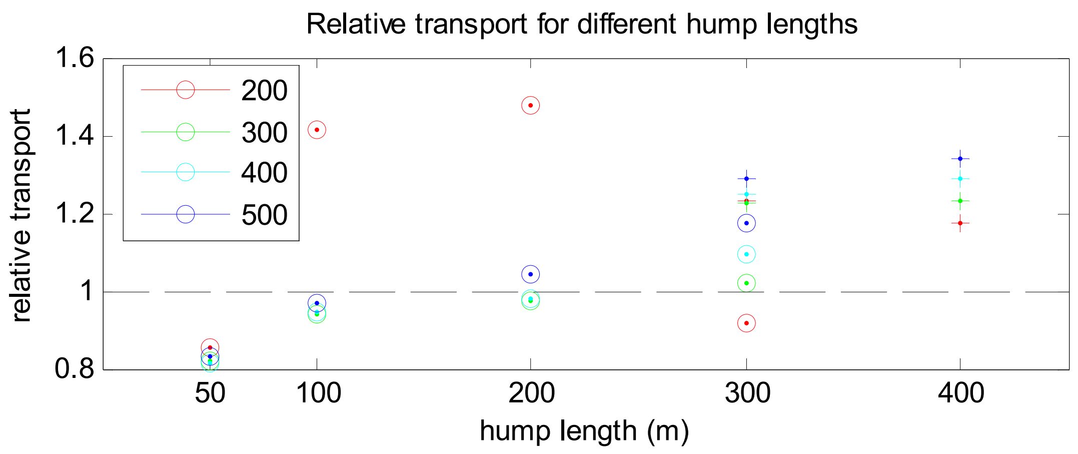


Figure 5-9 Relative transport onshore per nourished scenario, horizontal axes represents hump length, colours distinguish gap widths, circles are scenarios with 3 humps nourished and + represents the 2 humps scenarios

It can be concluded that only the scenarios for 200 and 300 meter humps are showing positive results. The scenarios with 2 humps show overall better results but are not applicable as extension to scenarios with more humps will not give similar results. Extension of the 3-hump scenarios will give less impact on the efficiency. Differences in hump number are clearly visible in the next figure, Figure 5-10. Clear is that the green and red line are hardly more efficient than the black dotted line. The blue line shows a much higher slope and is clearly more efficient than the other 3-humps scenarios.

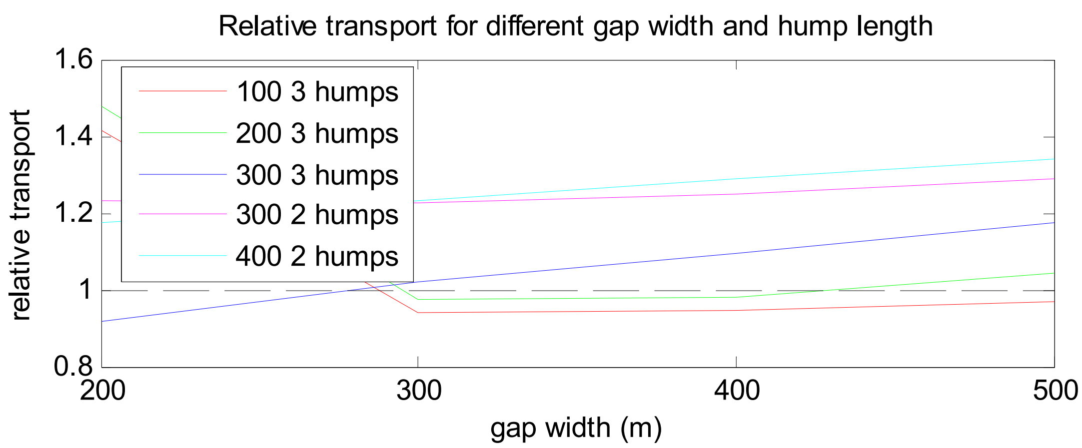


Figure 5-10 Relative transport onshore per nourished scenario, horizontal axes represents gap width, colours distinguish hump length and number of humps

Efficiency to nourished length of the different scenarios

The former analysis and efficiency parameter showed results relative to the nourished amount of sand. In most cases this parameter will do. More sand onshore with less nourished sand is the best result. In cases where a certain alongshore stretch of coast has to be fed, the nourished length is of importance as well. The following plots show efficiency on the hand of relative amount of sand going onshore per nourished length.

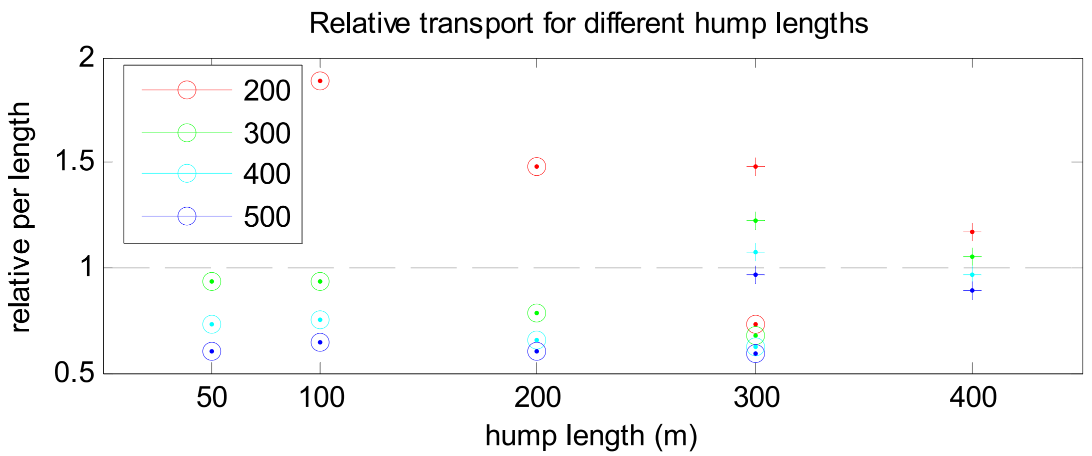


Figure 5-11 Relative transport per nourished length onshore per nourished scenario

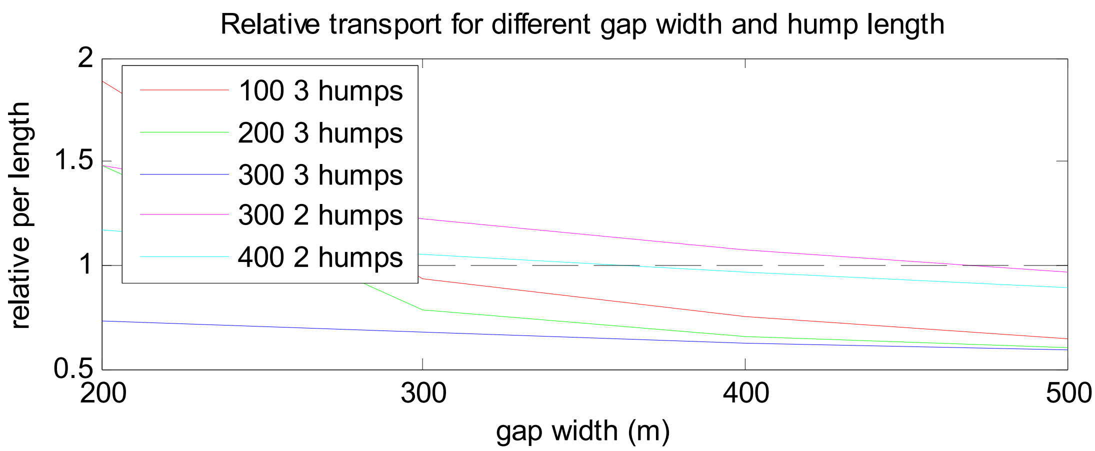


Figure 5-12 Relative transport onshore per nourished length, horizontal axes presents gap width, colours distinguish hump length and number of humps

Figure 5-11 and Figure 5-12 show that only in case of 2 humps a situation is obtained for which the relative transport per nourished length is higher. In most cases shoreface nourishments are executed being longer than 1000 meter, the efficiency of the reference nourishment will be smaller as well. It is assumed that the values which were plotted in the latter are giving good indication of the efficiency and that extension to longer bars or more than three humps will give comparable relative results.

Conclusion from the latter analysis is that a hump scenario with hump lengths of 300 meter and gap widths of 500 meter has the largest efficiency for the analysed scenarios. For a more efficient nourishment scenario in the form of humps it is clear from the latter initial analysis that the total nourished length should not be of importance. Only than humplike nourishing can be an option. For clarity a practical example is given in Appendix D-2.

5.2.4 Sensitivity of optimisation

The latter plots showed some clear results on humplike nourishing indicating that it indeed can be more efficient than bar nourishing of the shoreface. Before confirming this conclusion some sensitivity checks will be done on the evaluation method.

- Cross-shore transport on different locations on the crest of the nourishment to analyse the spatial dependency of the evaluation method;
- Chapter 4 showed a variation in time of the rip current for some scenarios with small gap widths. The sensitivity will be checked on this variation in time;
- The depth of the crest of the nourishment showed differences on hydrodynamics. For a depth of 3 meter the transport values will be compared with those for the 4 meter water depth.

As the method being used is mainly telling information about the overall, cross-shore behaviour of the humplike scenarios, it is worth checking the spatial variations on the crest. In appendix D-3 for four longshore rays the total cross-shore transport per nourished length has been illustrated as in the above. With reference on the middle of the crest (x = 1500 meter) the other rays lay on distances of 40 and 80 meters offshore from the crest centre and 40 meters onshore. The highest impact occurs on the middle section of the nourishments, more offshore (x = 1460 meter) and onshore (x = 1540 meter) the transports decreased in value. The patterns still show advantage in favour of the same hump sizes and the efficiency clearly depends on the implemented amount of sand. For the further offshore values (x = 1420 meter), the impact decreased significantly as the wave impact does not have so much more influence here. Most remarkable are the red dots for the 100 and 200 meter hump lengths. The rip currents showed some instable behaviour here, as was mentioned before; apparently this behaviour has a large effect offshore. Overall the spatial variation does not change conclusions.

The meandering of the rips showed some effect on the behaviour of some scenarios. This meandering has a period of approximately an hour. Appendix D-4 shows the variance of the transports for two moments in time. The magnitudes are the same for all dots, except for the 100 and 200 meter humps with gap widths of 200 meter. These scenarios showed the meandering of the rips and as a logical result into differences.

As was discussed before the water depth above the crest of the nourishments has large impact on the behaviour of the nourished sections and therefore on the transports. Appendix D-5 shows the variance of the values for depths of 3 and 4 meter above the crest. Remarkable is that the patterns are similar but that the red dots, representing the 200 meter gap widths give some clear differences for the 4 meter depth. Apparently the meandering does not occur on the 3 meter depths. The magnitudes of the transports for the 3 meter depth are approximately double the values for the 4 meter depth.

5.3 Trapping of sand as a result of humplike nourishing

Processes responsible for variation in the surf-zone were discussed in chapter 4 and will be analysed for the different humplike scenarios being discussed in this chapter. Of main interest is the behaviour of sediment trapping in relation with the gap width. Assumed is that larger gap widths lead to more penetration of the waves and therefore less distortion of the lee zone on average. Chapter 4 showed that the downstream humps have great influence as a result of breaking induced currents and interaction of waves.

The bar scenario showed small overall accretion in the lee zone of the nourishment. This accretion is overshadowed by the effect of the induced rips and conflicting currents to the south. Expectation for the actual situation is that variation of the angle of incidence for waves will result in variation of these perturbations in the vicinity of the bar heads. In contrast with this every single wave condition of a wave climate results in a longshore current being disturbed by the nourishment and sediment trapping occurs. Finally a gradual development of the shoreline with accretion in the shadow of the nourishment will be the result. Figure 5-13 shows the initial sedimentation and erosion plot for the overall area with the bar nourishing implemented; the right plot only shows values for the nearshore zone. It is clear that values are significantly smaller nearshore than on the nourishment itself, accretion as a result of sediment trapping is distinct.

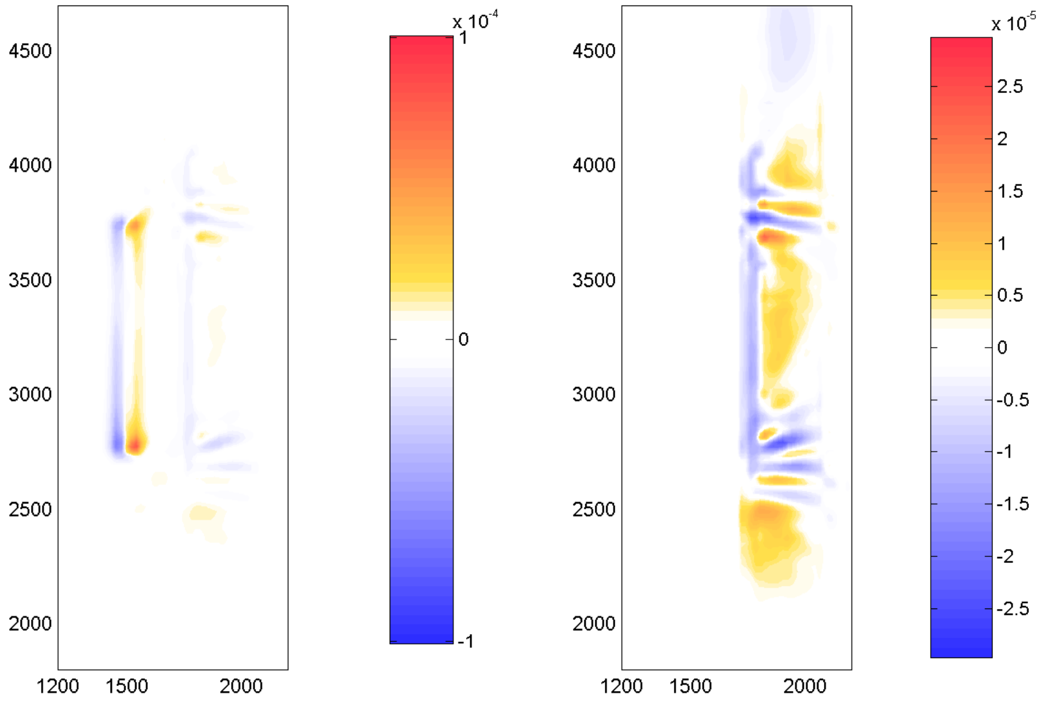


Figure 5-13 Sedimentation and erosion for bar nourishing, left plot shows overall pattern, right plot zooms in on magnitudes for nearshore zone. Magnitudes are in m/s, red is sedimentation, blue erosion.

For the humplike nourishing scenarios the same has been done as for the bar nourishing. The plotted figures show the sedimentation erosion plots for the hump scenarios of 100 and 400 meter length for different gap widths (Figure 5-14 and Figure 5-16) and the same plots with more accent on the nearshore zone (Figure 5-15 and Figure 5-17).

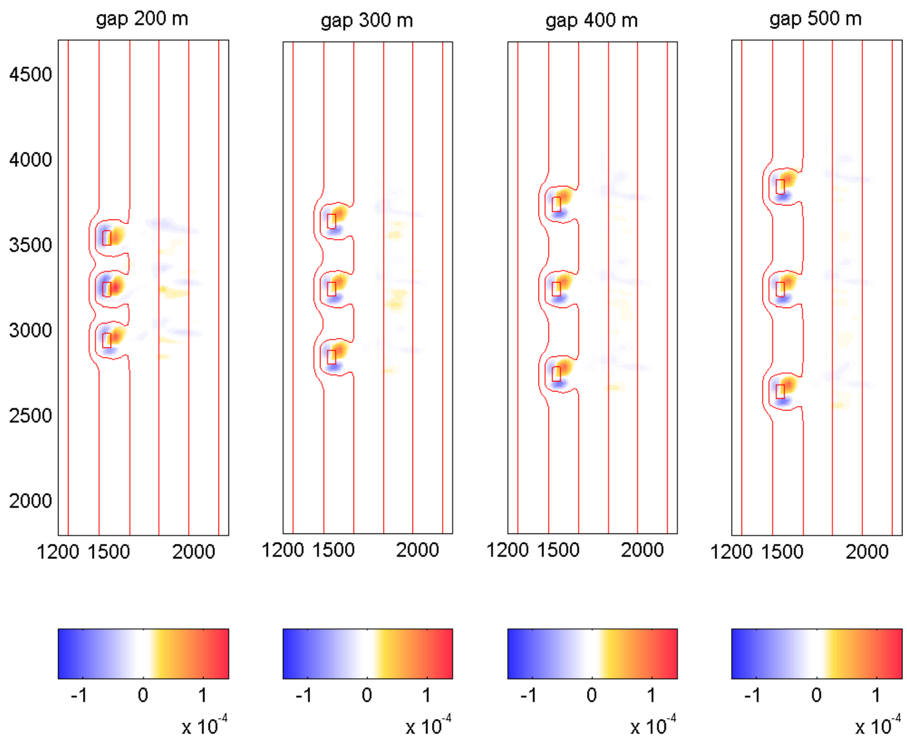


Figure 5-14 Sedimentation and erosion plotted for nourishing of the shoreface with hump lengths of 100 meter and a varying gap width. Values are for overall area in m/s.

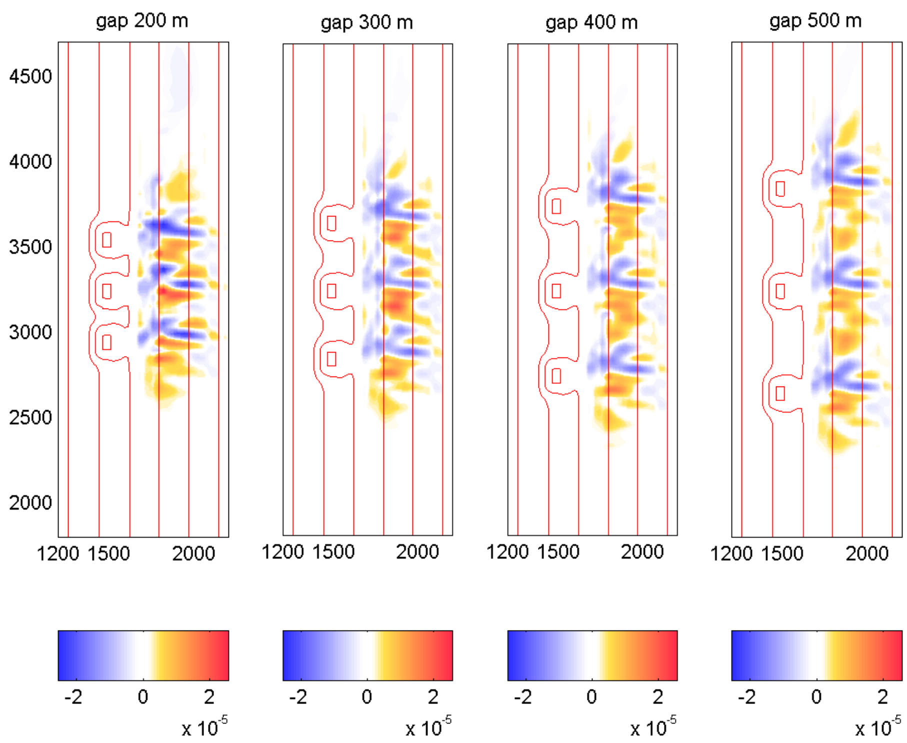


Figure 5-15 Sedimentation and erosion plotted for nourishing of the shoreface with hump lengths of 100 meter and a varying gap width. Values are for nearshore zone in m/s.

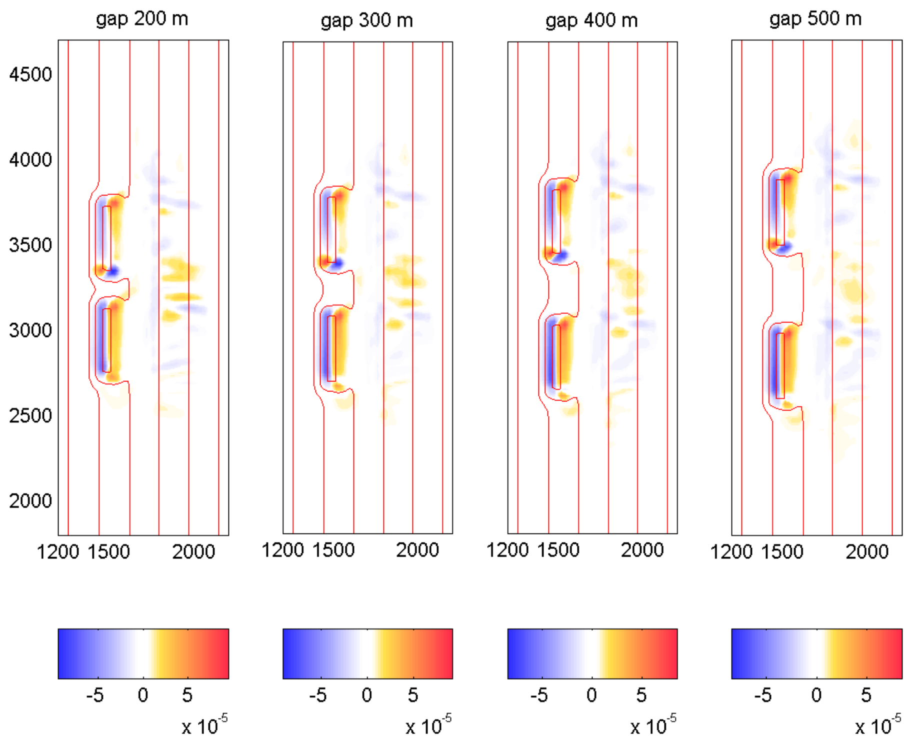


Figure 5-16 Sedimentation and erosion plotted for nourishing of the shoreface with hump lengths of 400 meter and a varying gap width. Values are for overall area in m/s.

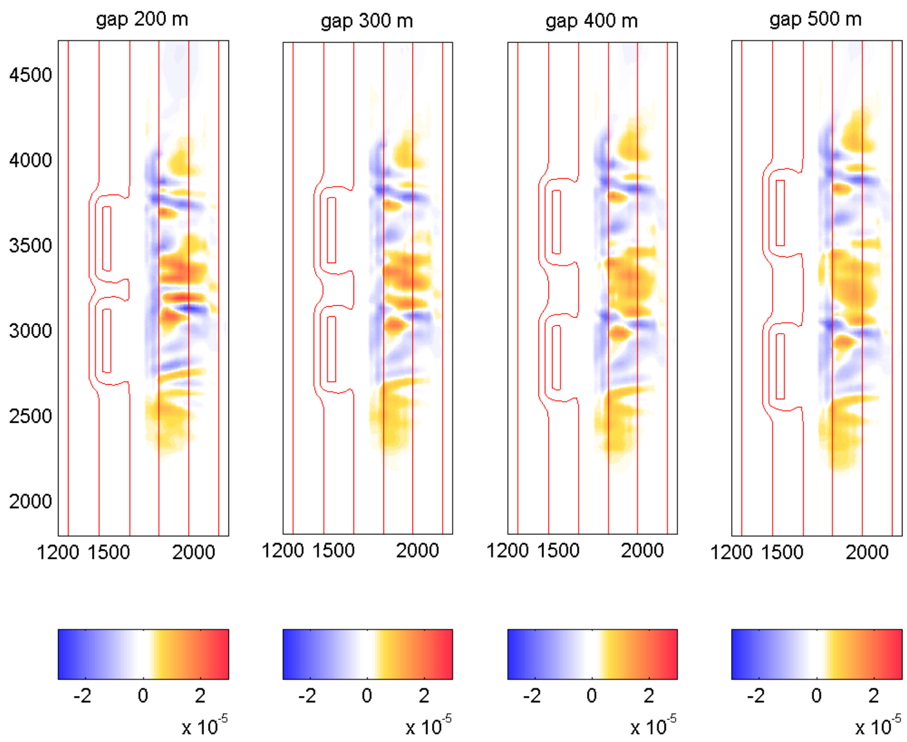


Figure 5-17 Sedimentation and erosion plotted for nourishing of the shoreface with hump lengths of 400 meter and a varying gap width. Values are for nearshore zone in m/s.

The figures show large differences with the bar nourishing results. Sedimentation occurs on large scale but is alternated by erosion spots. The gaps in between the humps will have a large contribution on the nearshore behaviour of morphology. Both for the 100 meter and 400 meter hump lengths changes are most intense for small gap widths. As the mutual distance is increasing the sedimentation and erosion shows similar patterns but the values are decreasing and surfaces are larger. The larger the gap widths are, the smaller the gradients in transports are in the lee of the humps.

The magnitudes of sedimentation and erosion are similar for the different scenarios. For the humplike nourishing method no clear sediment trapping occurs. Erosion spots are alternating sedimentation plots as the influence of the humps and gaps are changing per location. Different wave conditions will effect these locations even more and will spread the effect over the whole effected zone of the nourishments. Not clear is if this will overall lead to a gradual widening of the beach if so it is expected that the order of magnitude will be overall smaller than for the bar nourishing.

5.4 Synthesis

Variation of the hump properties shows differences in the efficiency of different scenarios. Especially the length of the humps will have large influence on the morphodynamic behaviour. The longer humps get the more resemblance with the elongated bar is seen and less cross-shore transport per nourished amount of sand is the effect. The contrast between humps within a scenario grows with longer humps as well. It was shown that the upstream hump has large impact on the behaviour of the downstream humps. This effect gets larger with longer humps.

The gap width showed less impact. A larger gap width was expected to create more space for the rip current to flow out so a less intense current should arise. This effect was only shown on small scale and did not result in significantly larger transport onshore. A trend is seen in the combination of gap width and hump length. The longer humps are the larger the influence of gap width is. This is caused by the effect of the rips getting larger when the humps get longer.

Optimisation shows that the shorter humps are, the larger the efficiency is as a function of the nourished length. Independent of dredging costs it obvious that more sand gain with less sand is always more positive from this point of view. The evaluation method showed that hump lengths of 300 meter fulfil this property no matter what the gap width and the number of humps is. The 100 and 200 meter scenarios showed large advantage as they use less sand. At the same time they have less gain of sand in the nearshore zone.

The nearshore effect of the humplike nourishing was dealt with in this chapter as well. The smaller the humps the larger the variations nearshore and disturbances as a result are. In the lee of the humps a chain of sedimentation and erosion spots is caused by the wave penetration and gradients in longshore transport. The larger the gaps are the more gradual the differences are. With longer humps increasing up to a bar more sand trapping onshore is expected than in the case of smaller humps. With different wave conditions large differences as a result of rips and contraction of currents are expected to be averaged over the whole coastline.

Mainly the cross-shore effect of the hump method is expected to gain more sand and act more efficient than the bar nourishing. The sediment trapping in the lee of the nourishments is smaller for the humplike scenarios. It should be taken in mind that sediment trapping always leads to loss of sand up- and downstream and therefore has only local advantage. If the objective is to get more sand into the beach profile over a longer stretch of coast humplike nourishing seems to be a good method.

6 Morphodynamics of humplike nourishments

6.1 Introduction

After analysing initial behaviour of shoreface nourishments in the latter chapters, morphodynamic behaviour is being analysed in this chapter. Conclusions being made until now are mainly based on cross-shore transports and showed advantage in case of the humplike nourishing.

Main objective for this part of the study is to show the efficiency of both bar nourishing and humplike nourishing after bottom changes due to morphodynamic modelling have been realised and compare those results. Attention will mainly go to the effects of the nourishments itself and not to their effect on the nearshore and shoreline. As morphodynamic results will show large disturbances will occur onshore and sediment trapping will be hard to distinguish. Analysing will be done only for exposure to single wave conditions. The same scenarios as dealt with in chapter 5 will be analysed.

Table 6-1 Shoreface nourishment scenarios for analysing of morphodynamics

	Number of nourishments	Length of crest (m)	Mutual Distance (m)
Bathymetry 2	1	1000	-
Bathymetry 3	3	100	200-500
Bathymetry 5	3	200	200-500
Bathymetry 6	3	300	200-500
Bathymetry 7	2	300	200-500
Bathymetry 8	2	400	200-500

Paragraph 6.2 will deal with the principles of morphodynamic modelling and the procedure and settings. Paragraph 6.3 deals with the morphodynamic behaviour for some scenarios and paragraph 6.3 compares the different scenarios for different conditions and shows the final efficiency of the nourishments after morphodynamic modelling

6.2 Morphodynamic modelling

Morphological acceleration factor

The sediment online version of Delft 3D, as it was described in Chapter 3, simultaneously computes sediment transport every time step and updates the resulting bottom. These bottom changes are simply the sum of the changes in bed load and suspended load per grid cell in time. For making computations more efficient the morphological acceleration factor has been introduced. Hydrodynamics only result in small changes of the bathymetry during hydrodynamic simulation time. By multiplying the changes of the bed by a constant factor a new morphological time-scale will lead to more efficient modelling (Lesser *et al.*, 2004).

$$\Delta t_{morphodynamic} = f_{MOR} \Delta_{hydrodynamic} \quad 6\text{-}1$$

The latter technique makes it possible to simulate morphological behaviour by only simulating a short duration for hydrodynamics. There is a limitation for the morphological acceleration factor as hydrodynamics are sensible for changes of bathymetry. In case the considered location is exposed to severe conditions and large changes are expected, a small factor has to be applied. If only small changes are expected the opposite is true. For coastal areas exposed to moderate tidal variation and wave exposure, a morphological acceleration factor of 50-100 can be applied.

For the case of the bar nourishing simulations have been done with different morphological acceleration factors (10, 25, 50 and 100). In a situation with 4 meter water above the nourishment and a wave of 2 meter high and an incident angle of 250 degrees, the development is shown after duration of 67 days of morphological computing (Figure 6-1). Bottom updating has not been executed during the first 240 minutes of hydrodynamic computing, during this spin-up interval hydrodynamic properties are able to reach the initially stable values before bottom level is changing.

The figures show negligible differences for the nourished sections for different morphological acceleration factors. In comparison with the initial situation clear morphological development is visible. In the vicinity of the shoreline more disturbances are shown. The larger the f_{mor} the less distinct changes are, the figures show how the red line shows much larger variations than the black line.

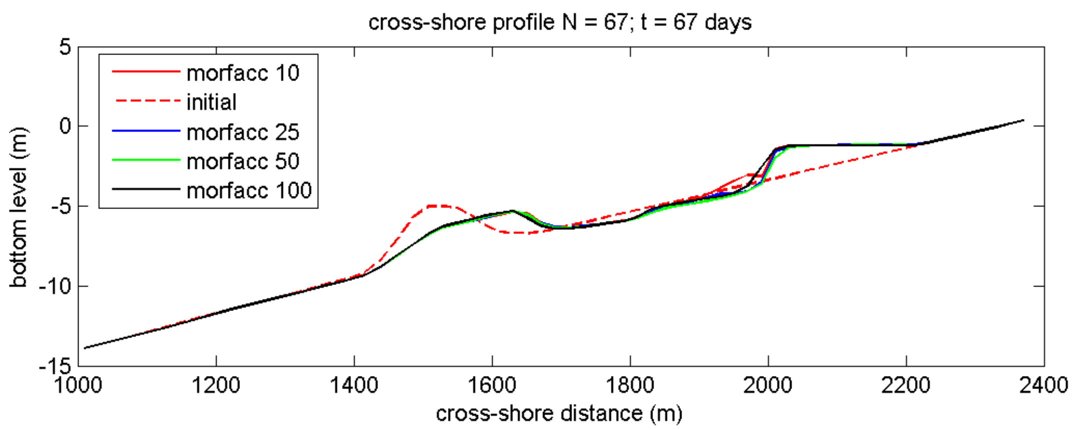


Figure 6-1 Cross-shore profile after 67 days of morphological simulating, cross-section at middle of the bar

For the current section a f_{mor} of 50 will be used, this factor shows good resemblance for the nearshore processes in comparison with the more accurate f_{mor} and provides extra efficiency in case of the simulation time.

Transport parameters

Figure 6-1 showed clear development of the nourished sections after 67 days of morphodynamic modelling. As later parts will show, the behaviour of the nourishments shows good resemblance with the expected behaviour. In contrast with this the breaker zone shows less plausible results. A large onshore transport here results in sandbar forming near the shoreline. This effect was already described in short in Chapter 3. Apparently the processes described by the transport formula do not give a good representation of nearshore processes in combination with depth averaged modelling (2DH). Calibration of the parameters was done in such a way that shoreface nourishments develop well in comparison with the 3D profile model.

Table 6-2 parameter settings for Figure 6-2 in which susw stands for wave related suspended load parameter.

	Sus	Bed	Susw	Bedw
0.8 0.7 0.2 1	0.8	0.7	0.2	1.0
1 1 1 1	1.0	1.0	1.0	1.0
1 1 0 0	1.0	1.0	0.0	0.0
1 0 0 0	1.0	0.0	0.0	0.0
0 1 0 0	0.0	1.0	0.0	0.0

Table 6-2 shows the dependency on the transport parameters as they were described in section 3.4.3. The figures represent 5 different configurations of the calibration parameters (Table 6-2).

- The blue line shows the parameter settings as they were applied for the latter chapters and the figures above.
- The red line represents the default settings of the transport model and lead to comparable results as in the situations applied before; morphological changes follow an equal pattern but are larger. Remarkable for the nearshore zone is that the shoreline is accreting faster but sedimentation erosion alternation and magnitude is much less. Wave effects seem to spread sand more gradual
- Comparing the red and the green line shows the impact of the contribution of the wave-related suspended load. Mainly in the breaker zone this difference is remarkable but around the nourishment differences are clear as well.
- The bed load parameter and wave related bed load parameter hardly show any contribution. The black line is in this case similar with the initial nourished profile.

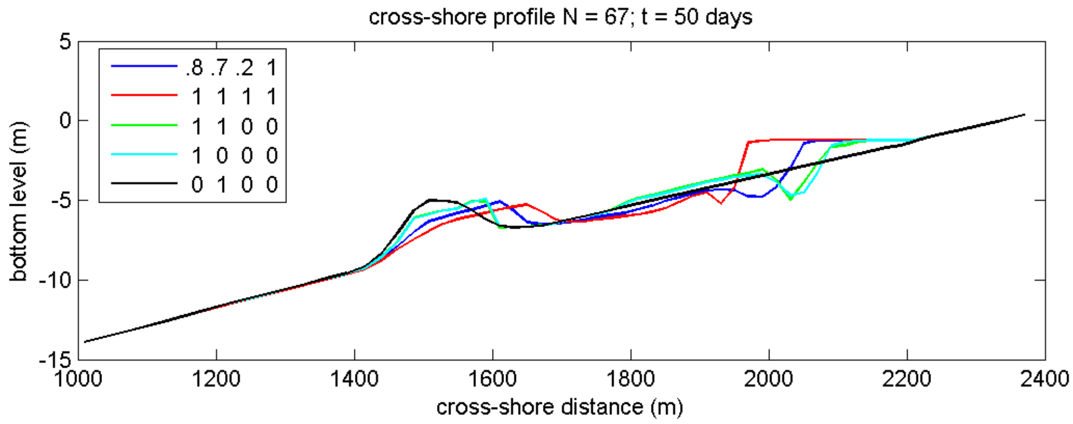


Figure 6-2 Cross-shore profile after 50 days of morphological simulating for different transport parameter settings

All settings show large changes in the nearshore zone. Onshore transport shows to be large in situations for which the wave related transport parameters (susw and bedw) are applied. In the cases with susw set on zero, no bar forming at the shoreline occurs. In contrast with this even larger disturbances are present in the nearshore zone than for the originally applied settings. The light blue line in Figure 6-2 shows this disturbance (2000-2200 m). Applying high wave-related parameters leads to a more gradual nearshore development. These properties make it hard to choose a setting. In the case with susw set on 0, the transport over the middle of the bar is almost negligible, appendix E-1 shows the difference for the two situations.

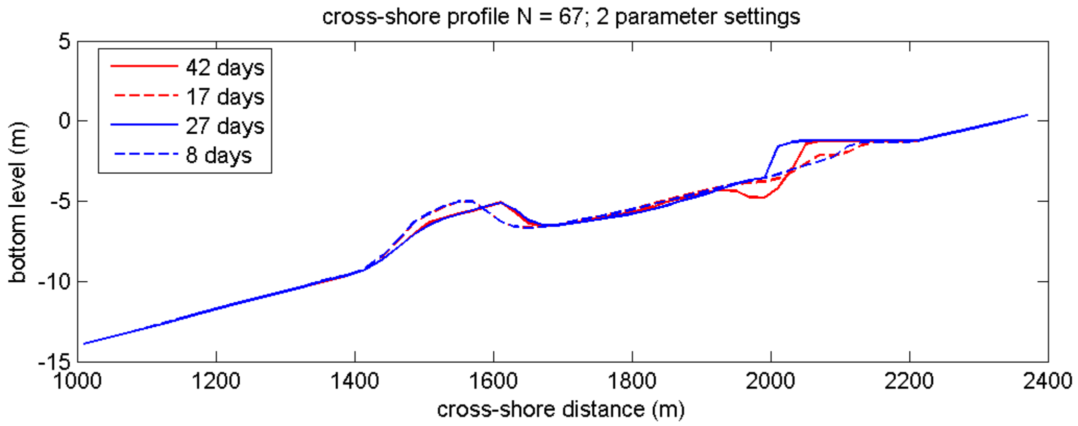


Figure 6-3 Time-scales for different parameter settings, blue lines setting 1100, red lines setting 0.8 0.7 0.2 1

Figure 6-3 shows a comparison for the default setting and for this study applied setting of the transport parameters. Remarkable is that with different parameter settings the same behaviour is seen for the nourishment but for a different moment in time. Apparently the time-scale is tuneable with the transport parameter settings as well. The same does not apply for the nearshore processes. The same parameter setting used for the former chapters will be used for the morphodynamic analysis. The magnitude of the individual bed load and suspended load transport gave reasonable values in comparison with the 3D-profile model. Expectation is that the behaviour of the shoreface nourishments will give reliable results.

Conclusion from the latter is that the 2DH model in combination with the parameter settings does not give accurate results for the nearshore zone but that the behaviour of the nourishments itself is modelled in a reliable way.

Reference subtraction

As the figures in the above showed, the nearshore zone shows significant accretion. Figure 6-4 shows the situation for the bar nourishing (red line) and the situation without any nourishing (blue line). Both show similar sedimentation, by subtracting the situation without nourishing from the nourishing situation the autonomous behaviour of the nourishments is obtained (green line). Development after more than 40 days still shows disturbance of the nearshore profile. The latter may be explained by the effect of sediment trapping but mainly horizontal circulations in the nearshore zone as a result of the nourished sections. From now morphodynamic behaviour of different scenarios is done by analysing autonomous development only. It should be considered that this autonomous behaviour of the nourishment is influenced by the effect of the nearshore bar forming. As the slope gets steeper the effect on hydrodynamics will get larger.

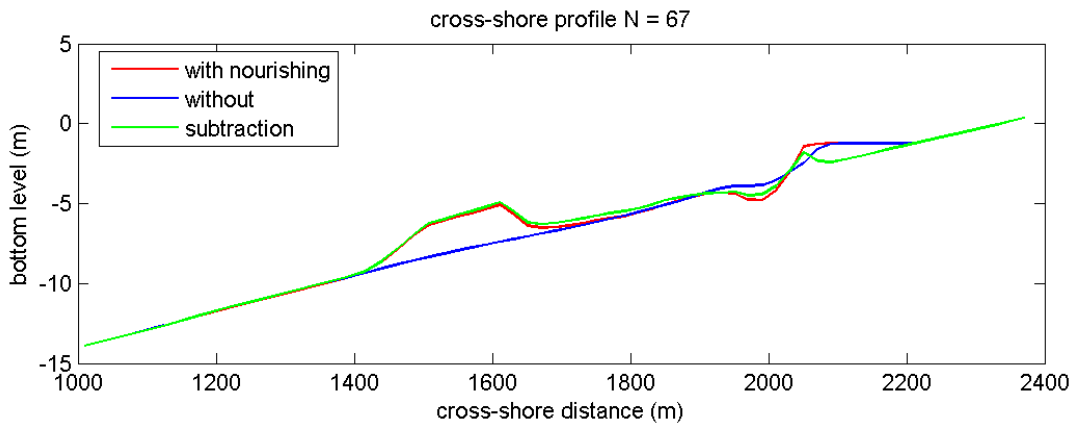


Figure 6-4 Cross-shore profile after 50 days of morphological simulation

Subtraction of the zero-situation leads to a good representation of the hump and bar development. The zero-situation shows similar disturbances on the shoreline as for the nourishment scenarios. At the southern lateral boundary small variations arise in cross-shore direction. Initially these velocities are negligible but morphological development increases these velocities, leading to significant transports and sedimentation and erosion. Analysing of the different scenarios will be hard for the nearshore zone and conclusions will be made on the hand of the already mentioned results. Figure 6-5 shows the autonomous bar situation after 42 days of modelling. Compare the figure with appendix E-1 for an idea of differences with original modelling results.

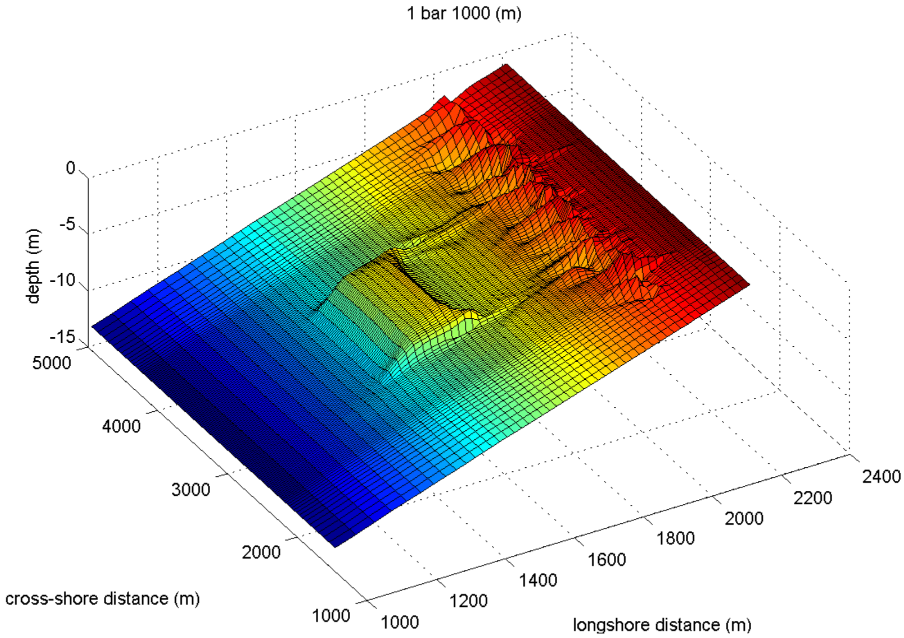


Figure 6-5 Autonomous bar situation after 42 days of morphodynamic modelling

For the morphodynamic modelling most parameter setting were dealt with in the previous. Table 6-3 gives a summary of the most important parameters.

Table 6-3 Parameter settings morphodynamic model

Parameter	**Value**	**Unit**	**Description**
Morfacc	50	-	Morphological acceleration factor
Spin-up interval	4	hours	Spin-up interval before morphodynamic computing
Total time	24	hours	Simulation time
	42	days	Morphological time
Sus	0,8	-	Tuning parameter suspended load
Bed	0,7	-	Tuning parameter suspended load
Susw	0,2	-	Wave related suspended load parameter
Bedw	1	-	Wave related bedload parameter
$alfa_{bn}$	1,5	-	Transverse bed gradient

6.3 Morphodynamic behaviour of humplike nourishing

Main objective for this part of the study is to obtain insight in the morphodynamic behaviour of the humplike nourishments. After the initial analysis a number of conclusions were made on the influence of hump length, gap width and the number of humps. It is expected that mainly in the beginning, just after nourishing of the shoreface, the impact is highest and the behaviour is most clear. Sand is redistributed into a more natural way fast and transports will decrease to lower levels.

Figure 6-6 shows the differences for the initial situation of the 1000 meter bar (left) and the bathymetry after 42 days of morphodynamic modelling after exposure to the same conditions. Although the units of the two different plots are different, comparison is possible. In the left plot it is seen how the tips of the bar move onshore much faster than the middle section does. The right plot confirms this behaviour, the tips of the bar indeed moved shoreward faster. This effect was described earlier ("boomerang effect") and it is now shown that morphodynamic modelling leads to the expected shape.

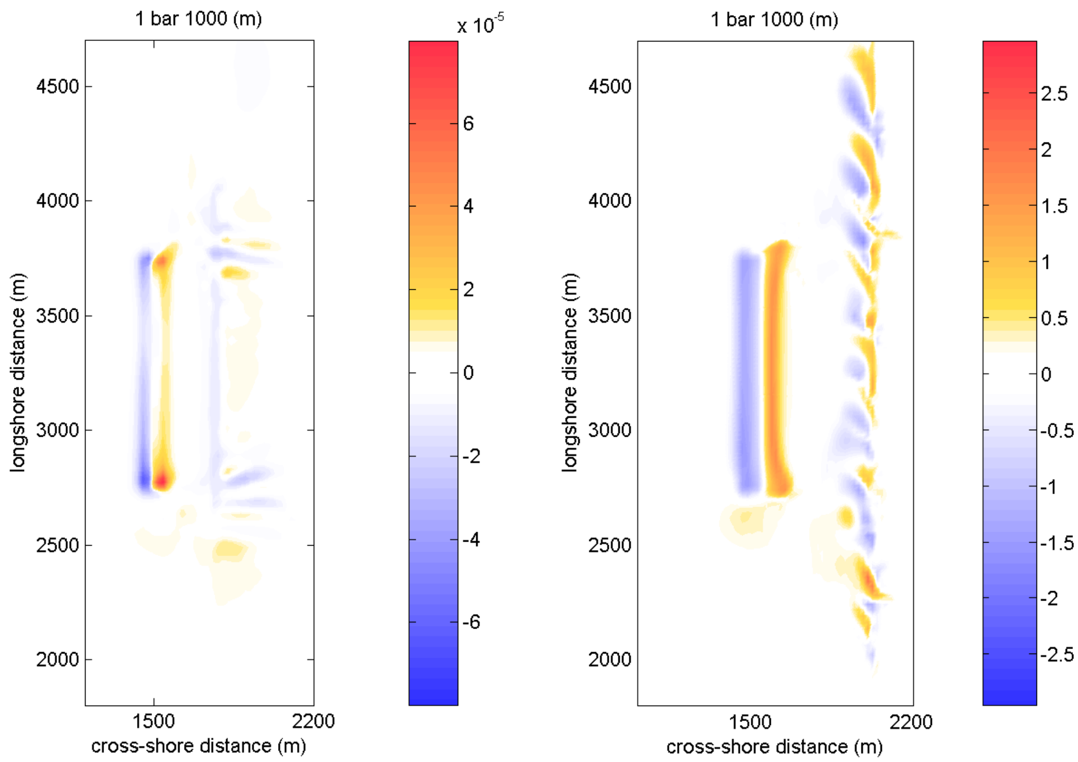


Figure 6-6 Differences in initial changes (m/s) and the cumulative bathymetry changes (m) after 42 days of morphodynamic modelling

The values from the initial sedimentation erosion figure are in the order of approximately 8.10^{-05} m/s. Over 42 days this rate would lead to far too high values for the bottom change. This confirms the effect of the initial behaviour being far more intense than the overall morphodynamic behaviour.

The cumulative bathymetry changes show expected values for the bar nourishment. In contrast with this the shoreline shows less resemblance with the on forehand expected pattern. Nearshore processes are disturbed at the boundary forming circulations at the shoreline. This effect is shown by the alternating erosion sedimentation spots as shown in the above.

6.3.1 Morphodynamic properties of humplike nourishing scenarios

Previous conclusions showed that the 300 meter hump scenarios result in the most efficient nourishing. Longer humps showed more onshore transport. Together with this larger gaps resulted in larger onshore transport as well. For the smaller humps gap width has less impact on the onshore gain of sediment. Appendix E-2 shows the cumulative erosion sedimentation plots for three different hump scenarios.

Hump length

Figure 6-7 and Figure 6-8 show the development of the humps for the two different hump lengths. Main difference, which can also be seen in Appendix E-2, is the difference in the northern and southern tips of the individual humps. For the 100 meter hump length the whole hump shifts onshore in the direction of the waves. This leads to a stronger onshore shift of the northern tip of the hump (green line) than for the southern line (blue line). The 300 meter humps behave different, a gradual shift of the hump occurs onshore. Only the southern hump seems to move offshore. This effect is seen for all the humps for these scenarios and is ascribed on the stronger rip effects as a result of more alongshore generated current at the crest of the larger humps. The smaller humps move more shoreward than the larger ones. Obviously smaller humps have less resistance.

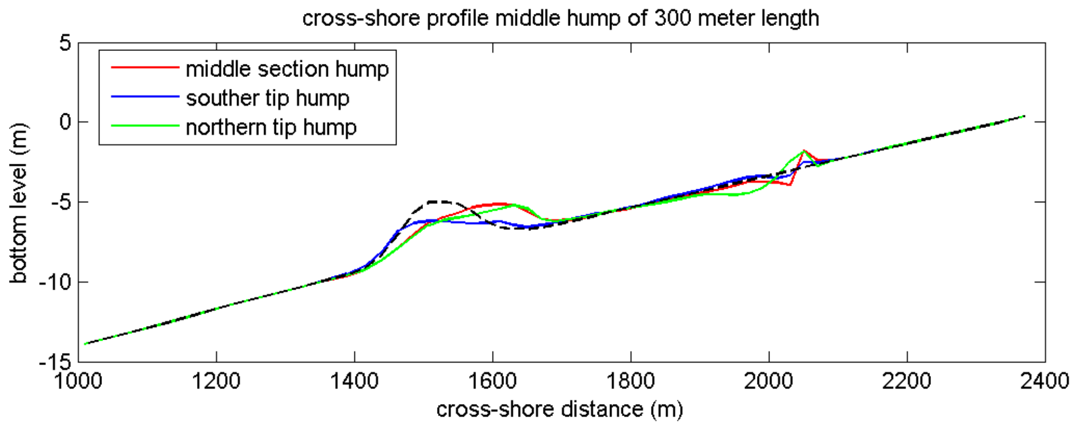


Figure 6-7 Bathymetry after 42 days morphodynamic modelling for 300 meter hump length, black dots represent initial situation

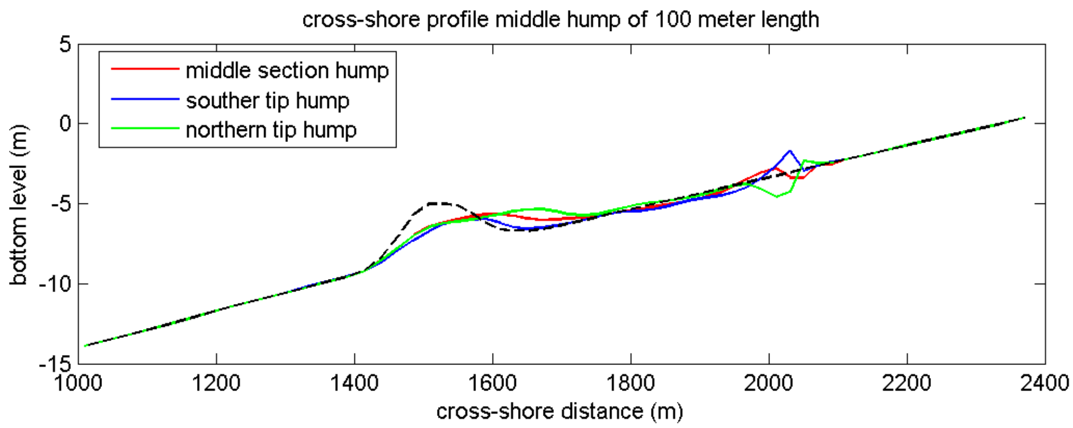


Figure 6-8 Bathymetry after 42 days morphodynamic modelling for 100 meter hump length, black dots represent initial situation

Gap width and number of humps

Chapter 5 showed large differences for the individual humps per scenario. The most southern hump is expected to develop onshore over the whole length whereas the downstream humps showed the described effect as a result of the rips. Figure 6-9 shows how the three humps within one scenario behave. In the figure the southern and northern hump tips are plotted for a scenario of 300 meter hump length and 500 meter gap width. Similar plots for different gap widths lead to the following conclusions:

- Differences between the humps within a scenario are small and are not expected to result in large variations between the upstream and downstream humps;
- Gap width variation leads to small differences in onshore shifting of the humps but do not result in larger differences between the humps within a scenario;
- The effect being discussed for initial cases is not applicable for the morphodynamic situation. For the initial analysis this led to large differences between 2- and 3-hump scenarios. For the morphodynamic situation this will be of minor importance.

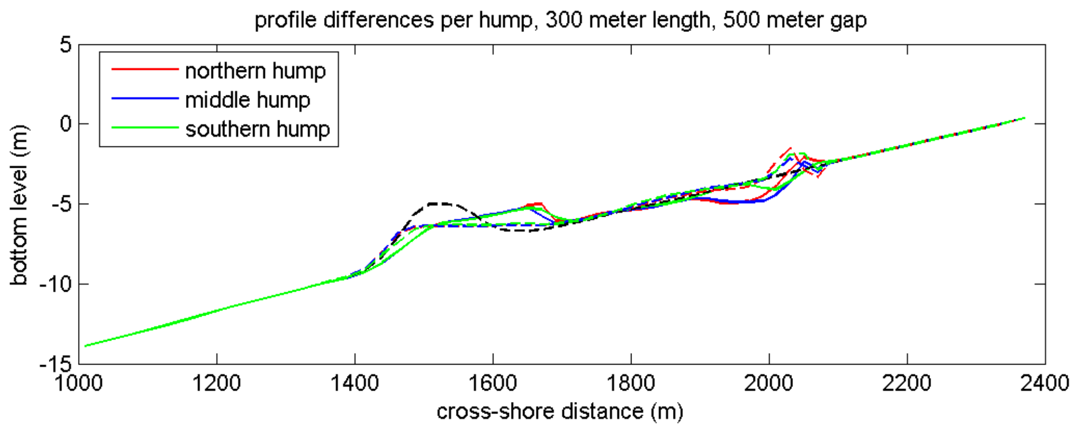


Figure 6-9 Comparison southern, middle and northern hump development for 300 meter hump length and 500 meter gap width (dotted lines southern hump tip solid lines northern hump tip).

Wave angle variations

The impact of different wave angles and wave heights is in general analysed by exposing the model area on a full representative wave climate. This was not done in this study, disturbances at the shoreline generate too large differences which will finally have their influence on hydrodynamics in the vicinity of the nourishments. In stead of a wave climate some different incident wave angles were modelled in combination with a moderate storm. These differences will show how the humplike nourishments react on different wave conditions and later, how the efficiency depends on it.

Appendix E-3 shows the morphological developed shoreface humps after exposure to different wave angles. In Appendix E-4 the cumulative sedimentation and erosion plots for these cases are shown.

Conclusions which were made in Chapter 5 are applicable for the analysis of exposure to different wave angles. With the 260 degrees incident wave, this is close to perpendicular, the humps shift onshore faster than for the case with more longshore approaching waves. In contrast with this the 240 degrees approach angle leads to more gain in the nearshore zone. The efficiency analysis will give more attention to this part of the modelling.

Remarkable fact is that the more perpendicular the waves approach the coast, the faster onshore the humps develop. For the longer humps the “boomerang effect” is recognisable for the more perpendicular approaching waves. The southern tips of the humps behave similar in all cases. Apparently the circulations cause similar patterns for all wave angles.

6.3.2 Sediment volumes

For comparing the different scenarios the volume changes of the sediment are computed for different sections of the modelled area. Per section the gain or loss of the sediment can be plotted. Figure 6-10 shows how the sections are chosen. The nourishments are executed in section A-G2, illustrated by the yellow block.

It is expected that section 2 mainly shows erosion and that all sediments from the nourishments are moving onshore to section 3. Sections 4 and 5 contain the zone in which the longshore current is expected to be most active and sediment changes as a result of circulations and contraction of currents occur. From the latter paragraphs it was shown that the nearshore zone gives less reliable results for exposure to waves only.

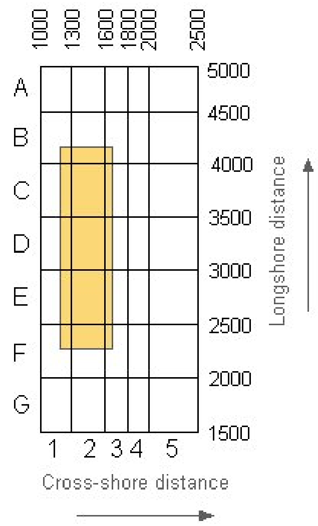


Figure 6-10 Sections for sediment volume computation

In Figure 6-11 the section analysis has been executed for two scenarios. In the left plot the bar nourishing is shown, the right plot shows the 3 times 300 meter humps with gap widths of 500 meter. This scenario showed to be the most onshore gaining variant after the initial analysis. Both scenarios use a similar amount of sand for execution.

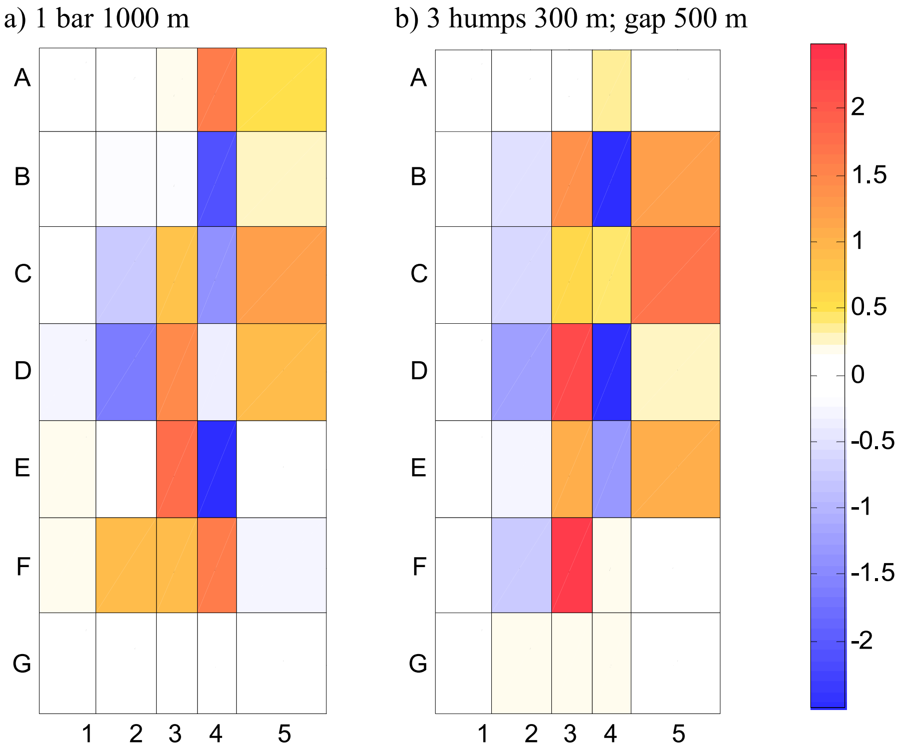


Figure 6-11 Volume change (*10^4 m^3) per section for the bar nourishing (left) and a 300 meter humplike nourishing (right)

The nourishing locations in the figures are clear by the distinct sedimentation- and erosion-sections. For the bar nourishing the bar lies in section CDE-2. The 3 humps in the right plot lie in sections B-2, D-2 and F-2. Table 6-4 shows the sedimentation and erosion of the different sections in values. For this table and the later analysis the sections A and G were left out of consideration to prevent that boundary disturbances have a large influence on the analysis. The different scenarios show large variations for the analysed sections.

Table 6-4 Sediment change per section (m^3), negative values represent erosion, positive is sedimentation.

Section		B	C	D	E	F
2	bar	9.000	1.300	-16.400	-7.300	-1.600
	humps	-7.900	-2.700	-12.100	-6.300	-4.900
3	bar	8.800	17.500	14.700	8.600	-1.900
	humps	23.500	10.400	21.800	6.100	13.500
4	bar	16.500	-25.300	-3.900	-13.700	-20.800
	humps	2.100	-13.100	-29.300	4.700	-25.900
5	bar	-2.800	700	9.500	12.000	3.100
	humps	-600	1.100	2.600	16.700	12.100

For section 2 the sections are loosing sand as a logical result of the nourishment lying in these sections. Obviously the sand is transported onshore to sections 3. These sections have a large gain of sediment. Section 4 on its turn shows mainly erosion. Here sand is transported both offshore and onshore as a result of cross-shore variations induced by circulations and contracting longshore currents. For the bar nourishing the rip currents are clearly recognisable for sections ABC-4 to the south and F-1234 to the north. The influence of the wave induced longshore current leads to sedimentation offshore on the southern part of the bar. This is why the section in which the southern bar tip lays (E-2) does not show clear erosion. For the humps processes are less good recognisable and only sedimentation in sections 3 is distinct.

A summation of sections will be used from now. Table 6-5 presents the sum of the longshore sections B-F for cross-sections 1-5. This results in 5 overall sections which will be used for further analysis of the efficiency of the nourishing scenarios.

Table 6-5 Sediment change per cross-shore section (m^3), negative values represent erosion, positive is sedimentation.

Section		1	2	3	4	5
	bar	-900	-14.600	46.400	-42.500	21.600
	humps	-1.500	-32.000	73.200	-56.900	40.300

The sediment volumes in Table 6-5 show that in section 3 significant sedimentation occurs as a result of the nourishments. In contrast with this section 2 shows clear erosion. Although the total volume of nourished sand is similar for both nourishments, the difference in volume increase for section 3 is remarkable. The erosion in section 2 for the humplike nourishing is more than twice the erosion of the bar nourishing. This is partly caused by the more efficient onshore transport effects, another effect is the strong rip resulting in offshore transports and bringing the sand from section 3 to section 2 again. Section 4 has a clear eroding character. Sand from this section is transported to both shoreward sections and offshore sections by wave induced processes. With these values for the 5 sections it is possible to compare all scenarios which were analysed before. This will be done in paragraph 6.4.

Development in time of sediment volumes

Plotting the volume changes of the sections 2-4 in time gives an idea of the development of the different sections and their influence on each other. Figure 6-12 and Figure 6-13 show this development for the bar nourishing and for humplike scenarios (hump length 300 meter) with gap widths of 200 and 500 meter (dotted lines). Figure 6-14 and Figure 6-15 illustrate the development of section 3 after every 7 days for the two scenarios. Analysing the figures the following can be concluded:

- During the first 25-30 days development is nearly constant and similar for the bar and humplike nourishing. During this period the nourishments shift onshore but the described bar heads and humps do not reach section 3 yet. Circulations in the nearshore zone move sand from section 4 to section 3 leading to clear sedimentation south of the bar and in between the humps;
- From 30 days the onshore transported sand originating for the nourishments start reaching section 3 and clear increase of sediment volumes are resulting. From now it is clear that the humplike nourishing gives different values for sediment volumes over the sections. Figure 6-14 and Figure 6-15 show this effect even better, it is clear how the humps reach section 3 faster and more even;

- In the onshore section 4 differences are seen from this moment as well. Disturbances at the shoreline reach section 4 from day 25 and cause significant erosion here. Sand is transported both onshore to section 5 and offshore to section 3.
- The differences between the 2 figures (Figure 6-12 and Figure 6-13) shows that small gap width results in similar behaviour with the bar nourishing. As the gap width increases the onshore transport of the nourishments it self does not change significantly but onshore changes are. Larger gap with leads to more sediment loss in section 4. This is the effect of stronger variations in longshore currents.

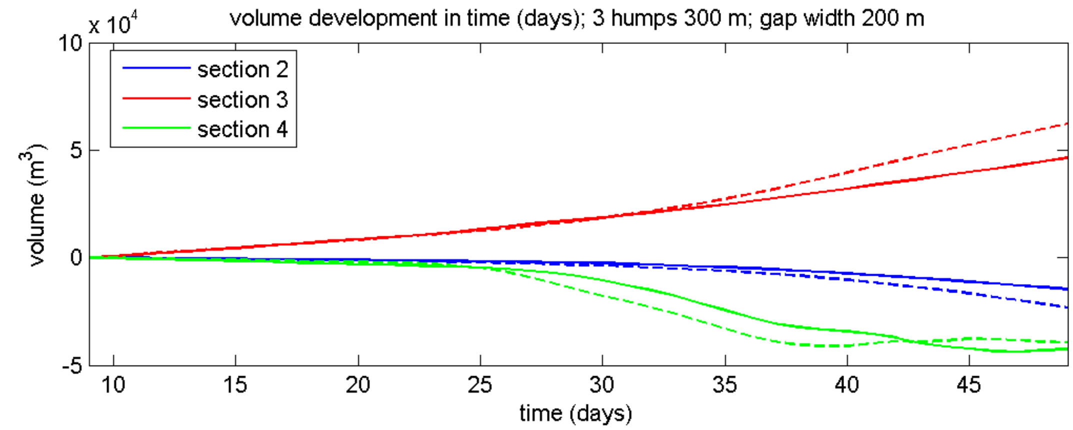


Figure 6-12 Morphological development of bar nourishing (solid line) and humplike nourishing (dots) for the 3 sections

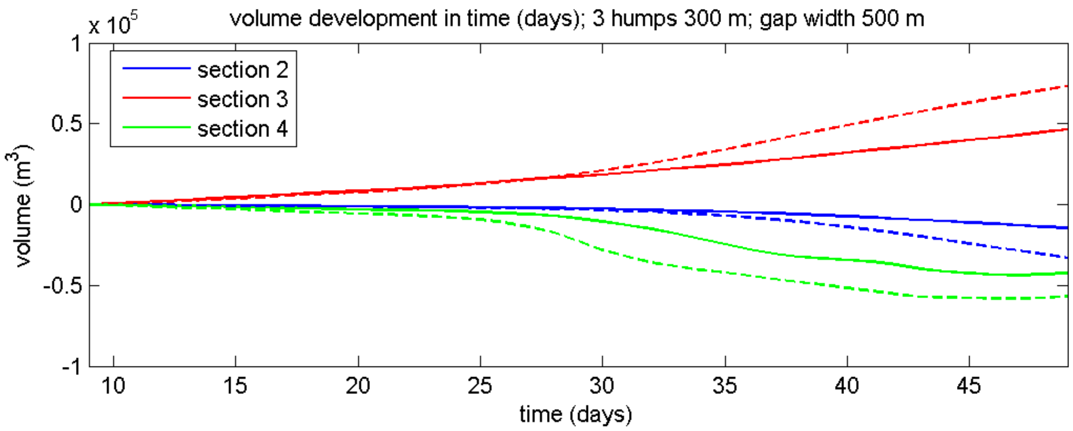


Figure 6-13 Morphological development of bar nourishing (solid line) and humplike nourishing (dots) for the 3 sections

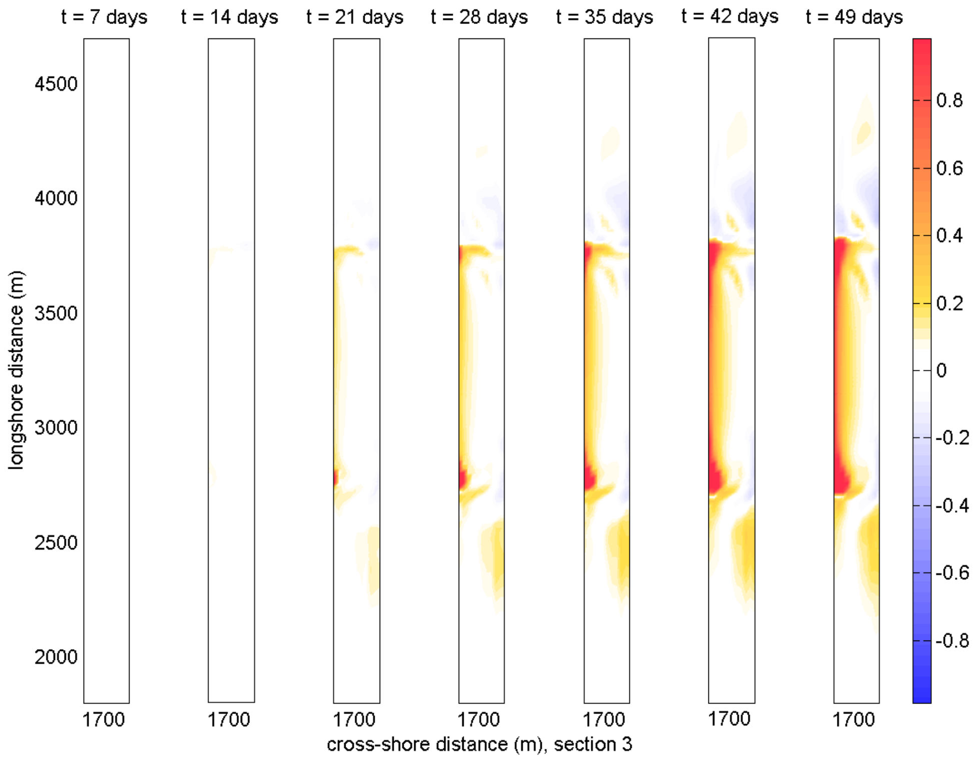


Figure 6-14 Development of sedimentation and erosion in section 3 for the bar nourishing

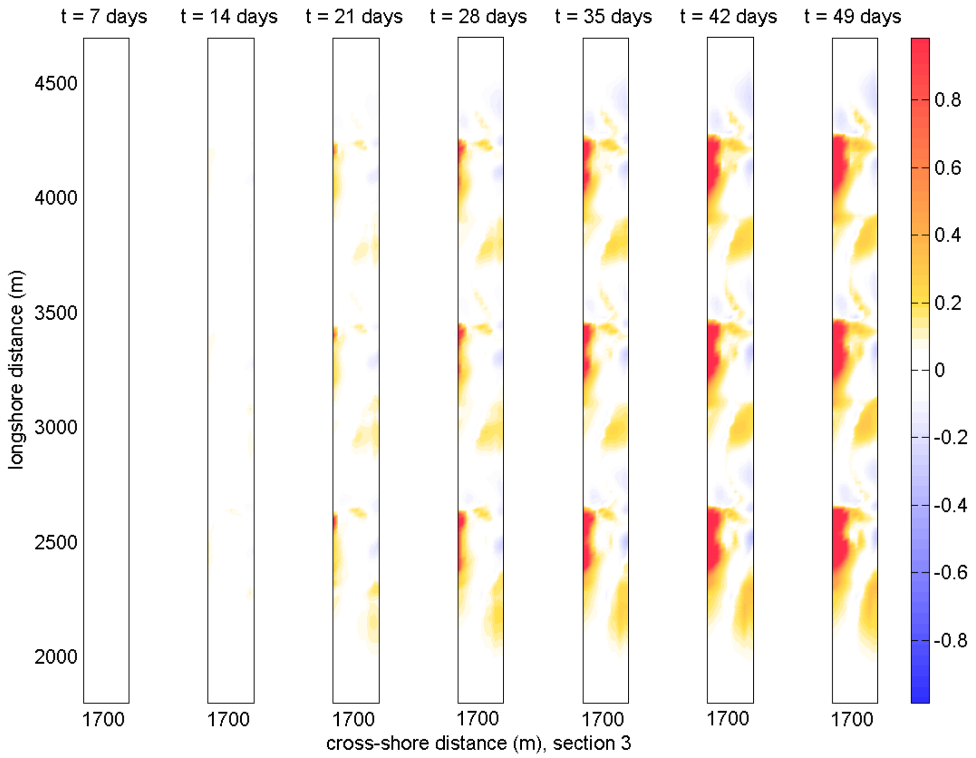


Figure 6-15 Development of sedimentation and erosion in section 3 for the humplike nourishing

Volume changes for different incident wave angles

Different wave angles showed different behaviour of the nourishment scenarios and will give different sediment changes per section as well. It is expected that more perpendicular waves will give more gain of sediments for section 3. Table 6-6 up to Table 6-8 show the sediment volume changes per section for the three different wave angles. For the humplike nourishing an increase of gain for section 3 is shown as the wave angles approaches more perpendicular. This was seen before as well and volume changes confirm the conclusion that more perpendicular waves increase the efficiency. For the bar nourishing values for section 2 and 3 stay more or less constant. A pattern for the onshore changes is not clear. Disturbances in the nearshore zone are significantly larger for the humplike nourishing. As was concluded in earlier sections these are expected to move more gradual with varying wave angles and water levels.

Table 6-6 Sediment change per cross-shore section (m^3) for waves with 240 degrees approach angle

Section		1	2	3	4	5
	bar	-1.900	-13.200	44.200	-12.500	5.500
	humps	-1.600	-23.900	65.500	-38.600	5.600

Table 6-7 Sediment change per cross-shore section (m^3) for waves with 250 degrees approach angle

Section		1	2	3	4	5
	bar	-900	-14.600	46.400	-42.500	21.600
	humps	-1.500	-32.000	73.200	-56.900	40.300

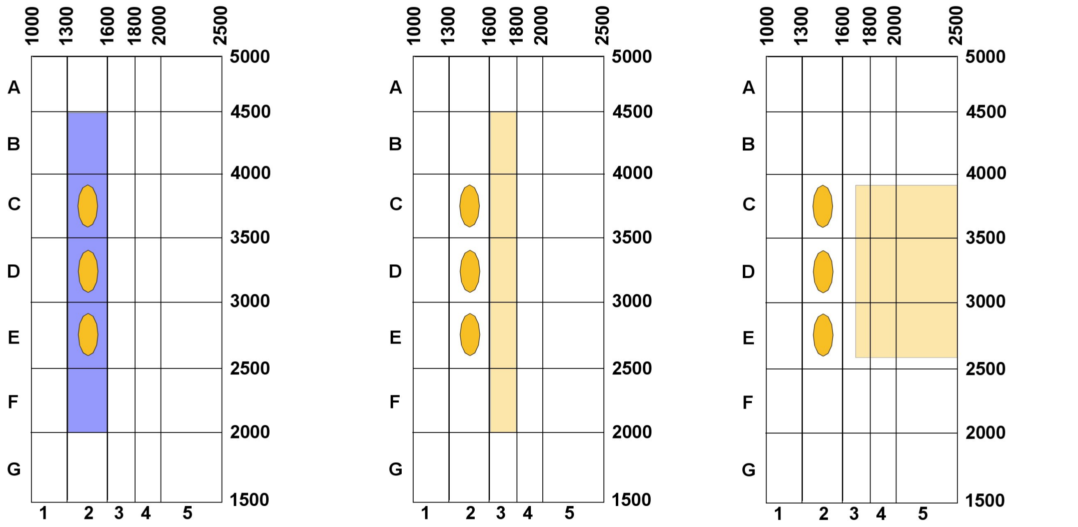
Table 6-8 Sediment change per cross-shore section (m^3) for waves with 260 degrees approach angle

Section		1	2	3	4	5
	bar	700	-19.900	47.200	-9.200	-6.000
	humps	-2.100	-60.500	97.500	-42.200	25.200

6.4 Morphodynamic efficiency of humplike nourishing

The previous part showed that the origin of sand is not clear for all sections. For determination of the efficiency three sections were considered (see Figure 6-16):

- Sand gain onshore, originating from the nourished sections is the intended positive effect. Best way to judge this is to compare the loss of sand in section 2. For this the assumption is made that the volume decrease of section 2 will unconditionally lead to gain onshore;
- Sand gain in section 3 is both a positive effect as a negative effect. This can be explained by the effect that sand is transported from section 4 to section 3 as well and is thus moving offshore;
- Trapping of sand in the lee of the nourished sections is a summation of the volume changes in the section onshore of the nourishments. The section is enclosed by the coastline, the x=1700 meter line and the northern and southern tips of the nourishments.



a) loss of sand section 2   b) gain section 3   c) sediment trapping onshore

Figure 6-16 Different sections for analysing

The scenarios as they were described before were all modelled for different wave angles leading to a collection of data points showing the efficiency per scenario. Figure 6-17 shows the efficiency of all nourishing scenarios. The values represent the percentage of the nourished amount of sand which moved out of the nourished sections, onshore. The different scenarios are distinguished by the hump lengths (100-400 m) along the horizontal axes; the gap width distinguished by colours (200-400 m) and the number of humps by '+' (2 humps), 'o' (3 humps). The efficiency of the bar nourishing is represented by the black dotted line, all points laying above this point result in more efficiency. Main conclusions from this figure are the following:

- First of all the largest onshore transport is obtained by applying a nourishment scenario with 200 meter humps and 500 meter gap widths. For this scenario app. 7 % of the nourished section is transported to the onshore sections after 42 days of morphological modelling. This in contrast with the bar scenario which only leads to a gain of app. 3 % (black dotted line)
- Larger gap widths overall lead to better onshore distribution of sand than the smaller ones. Mainly the differences between 200 meter gap widths and 300-500 meter gap widths are clear;
- Large gap widths also lead to large nourished lengths and thus distribution over a longer stretch of coast. If a particular part of the coast has to benefit of the nourishing this might be a disadvantage.
- The number of humps showed to be of large influence in the initial situation. For the morphodynamic situation this leads to values similar for 3 as for 2-hump scenarios. Extension to more humps in a chain will lead to the same values.

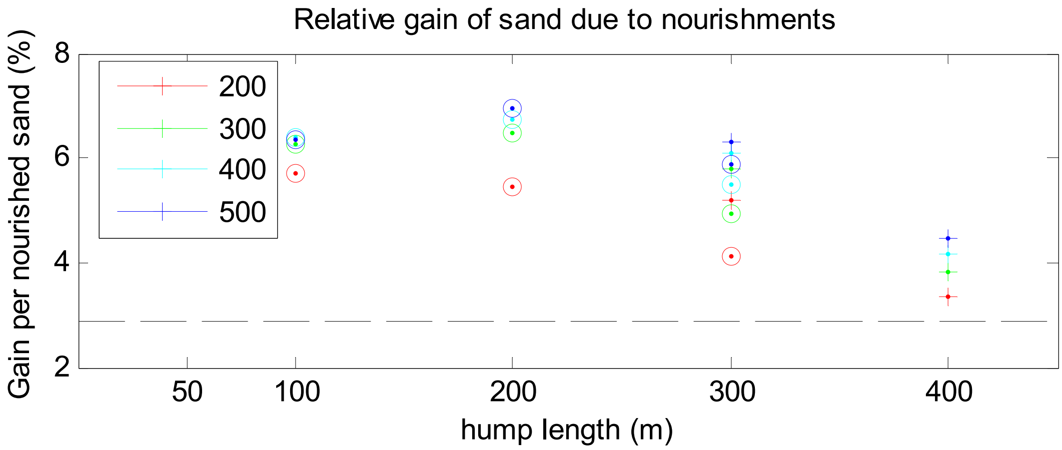


Figure 6-17 Relative gain onshore due to losses in section 2, different colours represent the different gap widths of the scenarios

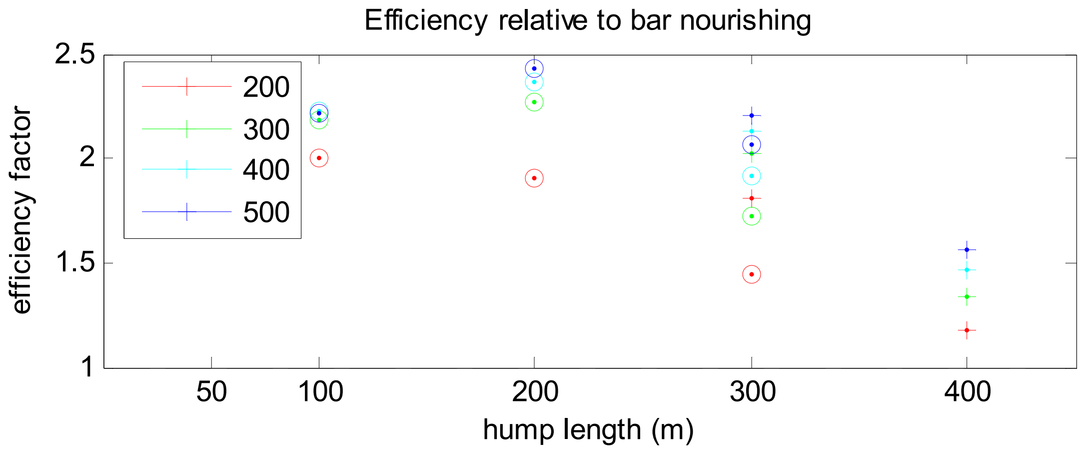


Figure 6-18 Efficiency per scenario divided by the bar nourishing efficiency

Figure 6-18 shows the values per scenario of Figure 6-17 divided by the efficiency of the bar nourishing. The optimum scenario for a incident wave angle of 250 degrees has an efficiency which is 2,5 times larger than the efficiency of the bar nourishing. Table 6-9 shows the optima for the other incident wave angles.

Figure 6-19 shows the relative gain of sand in section 3 which is just landward of the nourished sections. Sand volume differences in this section are caused by: a) nourished sand shifting onshore, b) trapping of longshore sediment and c) moving offshore of sediments from more onshore sections. The latter contribution is initiated mainly by horizontal circulations due to the nourishments. Figure 6-14 and Figure 6-15 showed the development of section 3 in time and gives a clear idea of locations of sedimentation due to nourished sand and other processes.

Comparing the values for section 2 and 3 it is seen that gain in section 3 is much higher than losses in section 2. As it was mentioned before it is hard to make conclusions out of Figure 6-19. For larger hump lengths more sand gain from onshore sections and longshore trapping occurs. The optimum hump scenario, using section 3 as measuring section, would be the 300 meter hump length with the widest gap.

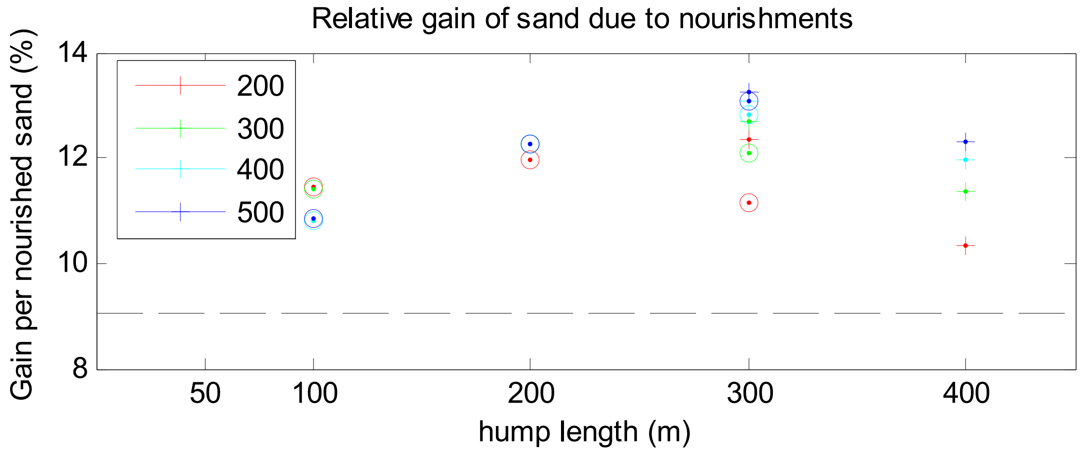


Figure 6-19 Relative gain in section 3, different colours represent the different gap widths of the scenarios

Sediment trapping

The summation of sand volume changes onshore of the nourished sections leads to the values plotted in Figure 6-20. The figure shows values for an incident wave angle of 240 degrees. With more alongshore incoming waves sediment trapping is more clear and patterns are better seen. The figure shows how the nourished bar traps approximately 1.10^4 m^3 sand in 42 days of moderate storm conditions. This is of similar amount with the onshore transported sand from the nourished bar ($1,3.10^4$ m^3). For the humplike scenarios it is clear that less sand is being trapped onshore and that even loss of sand is seen. From this it can be concluded that sediment trapping for the humplike nourishing is indeed less than for the bar nourishing method. A possible reason for this could be the larger offshore transport due to wave penetration through the gaps and the generating of circulations onshore. In the figure clear trends are seen for the different gap widths, a wider gap leads to more erosion onshore instead of sediment trapping. This confirms the conclusion of wave penetration causing onshore erosion. The onshore erosion partly explains why the gain of sediment in section 3 (Figure 6-19) is larger than the loss in section 2.

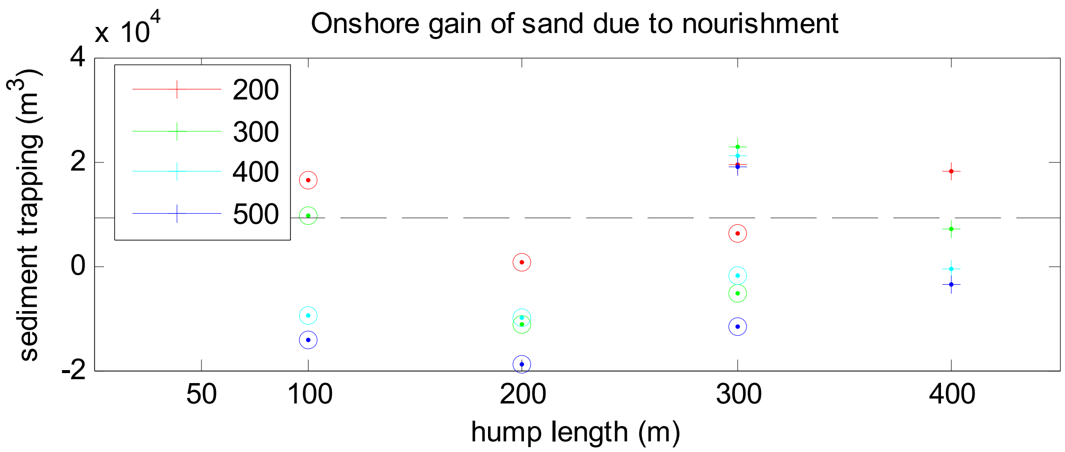


Figure 6-20 Relative trapping due to nourishment scenarios, different colours represent the different gap widths of the scenarios

The cumulative sedimentation and erosion plots show large disturbances onshore which are expected to give a false representation of the actual behaviour. The conclusion of sediment trapping onshore of humps being smaller than for bar nourishing is confirmed by the previous. Disturbances are averaged over the section onshore and therefore it is expected that it has little impact on this conclusion.

Wave variation

Appendices E-5 and E-6 show the same plots as the latter for incident wave angels of 240 and 260 degrees. For determination of the efficiency relative changes in section 2 were applied as these give the most certain results of nourishing behaviour. The results are similar as for the 250 degrees wave angle, largest efficiency is obtained with gap widths of 500 meter. Table 6-9 shows per wave angle the most efficient scenario with its efficiency in comparison with the efficiency of the bar nourishing.

Table 6-9 Maximum efficiency per wave angle

	Most efficient hump length	**Efficiency (%)**	**Efficiency bar nourishing (%)**	**Efficiency factor**
225 degrees	100 meter	5,3	2,9	1,8
240 degrees	200 meter	5,3	2,6	2,0
250 degrees	200 meter	6,9	2,8	2,5
260 degrees	300 meter	11,2	3,9	2,9

For the more perpendicular waves the efficiency is highest. It is clear that the more alongshore wave conditions dominate the wave climate the less efficient the humplike nourishing gets. However, the 240 degrees wave angle still shows an efficiency which is twice higher than the bar nourishing. For a more complete picture of efficiency with varying wave angles the 225 degrees wave angle was added as well. The table shows constant values with different incident wave angles for the bar nourishing whereas the humplike nourishing shows clear decrease. For the more shore normal approaching waves efficiency is higher for the shorter humps.

The onshore distribution of sand as a result of shoreface nourishing indeed is more efficient by applying humplike nourishments. It is recommended to model the humplike nourishments under exposure to a better describing wave climate to investigate the overall efficiency for a longer period of time.

Waterlevel variation

For the bar scenario and a humplike scenario of 200 meter hump lengths and 500 meter gap widths simulations were executed with a varying waterlevel. Distinction was made between a situation with and without horizontal tide:

- Tidal amplitude of 1 meter with a period of 12 hours and no horizontal velocities, meaning that there is no phase difference between the lateral boundaries;
- Tidal amplitude of 1 meter with a period of 12 hours including horizontal velocities, a tidal wave of 400 km was applied leading to 3,15 degrees phase difference between the lateral boundaries.

For both conditions the average waterdepth was set on 5 meters above the nourished sections. This means that only a small period of time water depths of 4 meter are present. Conclusions of initial behaviour showed that the shallower the water above the humps, the less efficient humps get and the smaller the advantage in comparison with bar nourishing is. The advantage of humplike nourishing is obtained during low water tide. Appendix E-7 shows the humplike situation after 25 days of morphodynamic modelling in comparison with the situation with a constant waterdepth of 4 meter above the nourishments. Some general conclusions of these plots are the following:

- The humps shift onshore less fast than in the situation with constant low water level. For determining the efficiency of the scenarios after exposure to tide a longer term should be modelled. The modelled short term showed faster relative onshore shift for the humplike nourishing than for the bar nourishing;
- The relative onshore efficiency shows to be a little less for a situation with horizontal tide included. Mainly the downstream site of the humps and bar show more longshore distribution of sand and therefore less onshore transport;
- Erosion and sedimentation alternation is spread over the inter-tidal beach zone; the nourished sections move onshore more gradual.

The fact that humplike nourishing only gets more efficient with shallower water leads to the conclusion that the values computed in Chapter 6 may be too high but give a good idea of the efficiency of humps.

6.5 Synthesis

The different scenarios give an idea of the improvement of the efficiency of the nourishing method for different dimensions and whether the hypothesis is right or not. Figure 6-17 collects all data of the different modelled scenarios into one plot and shows an optimum for humps with 200 meter hump length and 500 meter gap width. The best hump length showed to be dependent on the incident wave angle. A length of 200 meter will overall give good results. Gap widths ranging from 300-500 meter showed to give only little difference. Larger gap widths do give better results but cover a larger stretch of coast. A choice has to be made between widening a certain part of the beach and gaining or much sand onshore as possible. For the second option humplike nourishing gives good results. In comparison with the efficiency analysis for the initial behaviour it shows that humps behave even better than the initial analysis showed.

It should be considered that this is only the optimum for single wave conditions over a period of 42 days. Variation in wave angle showed overall positive results for the humplike nourishing. More shore normal wave angles showed more onshore efficiency. The schematisations showed that onshore transport due to humplike nourishing is larger than transport as a result of bar nourishing. Variations in the nearshore zone did not result in clear patterns for hump length and gap width.

7 Conclusions and Recommendations

7.1 Conclusions

Both the initial sedimentation and erosion analysis and the morphodynamic analysis have shown that humplike nourishments have a clear advantage over traditional bar nourishing. More sediment is moving onshore per nourished amount of sand in case of humplike nourishing, which confirms the hypothesis of this report. Besides this main conclusion a number of sub conclusions is listed below:

Literature

- The final budget in the nourishment zone increases after implementation of a nourishment in the form of a feeder berm. Finally an amount of 50-70 % of the initially nourished sand is still in the nearshore section after 3-5 years
- For the Delfland en Egmond shoreface nourishments clear accretion onshore has been seen at the tips of the nourished bar. Waves breaking at different locations cause water level variations in alongshore direction. The concentrated current over the bar edges leads to complex circulations onshore and offshore directed rip currents. Vertical velocity distribution changes in the rip and leads to more onshore transport over bar edges than offshore transport in the rip channel (Drønen *et al.*, 2002).

Initial behaviour

- Modelling of bar nourishments shows that the bar heads move onshore faster than the bars' middle section;
- Rip currents have little impact on onshore transports. Rip currents flow offshore at deeper water where sediment concentrations are low and little transport is the result;
- Incident wave angle shows to be of large influence and a main determinant of the behaviour of the nourished humps. The more perpendicular to the coast waves approach, the more favourable humplike nourishing is compared to nourished bars;
- Higher waves and shallow water result in higher water level gradients leading to increased onshore transport in case of humplike nourishing;
- Initial transport shows the highest efficiency for hump lengths of 300 meter. Efficiency is formulated as the cross-shore transport over the crest of the nourished section normalised to the nourished amount of sand;
- The longer the humps are the larger the influence of the gap width is. The scenarios are analysed with gap widths of 200-500 meter. Wave induced rips effect the transport on downstream humps, with larger gaps this offshore current has less influence;
- Humplike nourishments lead to alternating erosion and sedimentation spots which are expected to be averaged by a wave climate with varying wave properties leading to more gradual development.

Morphodynamic behaviour

- Morphodynamic modelling confirms the conclusions of the initial sedimentation and erosion analysis. Humplike nourishing leads to more sediment transport onshore;
- A clear optimum was found for the hump length and gap width. A hump length of 200 meter with a gap width of 300-500 meter gives the best results. Longer humps start behave like bar nourishments and shorter humps use too much amount of sand in relation with the efficient length of the hump;
- For bar nourishments, onshore transport showed to be approximately constant for different incident wave angles. In contrast with this, humplike nourishing clearly shows greater efficiency for the more perpendicularly approaching waves. In case of waves approaching with 45 (225) degrees to the shore normal the humplike nourishments showed to be 1,75 times more efficient. For more perpendicular waves this value increases up to 3 times larger.
- Nearshore behaviour was hard to get a grip on with morphodynamic modelling. Large disturbances were shown here in the form of sedimentation and erosion spots which were not considered to be realistic;
- Averaging the nearshore behaviour over a section in the lee of the nourishments, it was seen that humplike nourishments have a negative influence on sediment trapping. In comparison with the conventional bar nourishments, erosion occurs in this region which is probably caused by wave penetration and offshore transport of sediments. As a logical result larger gap widths between humps result in less sediment trapping.

7.2 Recommendations

The previous section confirms the formulated hypothesis 2.4, humplike nourishments are indeed potentially more efficient than bar nourishments. It should be considered that the analysis was based on rather simplified schematisations of the coast and boundary conditions. The model applied is able to predict behaviour of shoreface nourishments in a realistic way. However, results were only compared relative to prevent model errors from having too much impact. Sedimentation and erosion in the nearshore zone are considered unrealistic and a model, describing this part of the coastal zone better, would be a good improvement. More research is needed on the actual behaviour and the influence on the shoreline, for this the following recommendations are made:

<u>Perform a follow-up study including realistic schematisations of bottom and boundary conditions with as objective to model the actual behaviour of humplike nourishments.</u>

- By using an existing bathymetry and boundary conditions determinative for the covered coastal area real data can be used to calibrate the model and have more realistic results. The new model should describe a smooth bathymetry so the behaviour of humplike nourishing can be analysed without the complex influence of natural bar systems;
- For obtaining a more realistic description of transports and 3D modelling should be considered. Depth averaged modelling (2DH) showed difficulties with fine tuning of cross-shore transports in the breaker zone. Overestimating of this transport was resolved by only analysing the autonomous behaviour of nourishments;
- New modelling should contain longer term predictions. The present study mainly paid attention to initial and short term behaviour.

<u>Execution of a pilot project in combination with a high resolution monitoring program.</u>

- For this pilot project a row of three humps with a length of 200-300 meter should be sufficient to get valuable data for hindcasting studies.

References

Aagaard, T., Greenwood, B. and Nielsen, J., 1997. Mean currents and sediment transport in a rip channel. Marine Geology 140, 25–45.

Brander, R.W. and Short, A.D., 1999. Morphodynamics of a large-scale rip current system at Muriwai Beach, New Zealand. Marine Geology 165 (2000), 27-39.

Chen, Q., Dalrymple, R.A., Kirby, J.T., Kennedy, A. and Haller, M.C., 1999. Boussinesq modelling of a rip current system. Journal Geophysical Research, 104(C9): 20,617-20,638.

Dalrymple, R.A., 1978. Rip currents and their causes. Proceedings 16th International Conference Coastal Engineering, American Society of Civil Engineers, Hamburg, 1414-1427.

Dronen, N., Karunarathna, H., Fredsoe, J., Sumer, B. M. and Deigaard, R., 1999. An experimental study of rip channel flow. In Coastal Engineering 45, pp. 223-238.

Grunnet, N.M., Walstra, D.J.R. and Ruessink, B.G., 2004. Process-based modelling of a shoreface nourishment. Coastal Engineering (in Press)

Haas, K.A. and Svendsen, I.A., 2002. Laboratory measurements of the vertical structure of rip currents. Journal Geophysical Research, 107 (C5) pp. 15-1 - 15-20.

Haas, K.A., Svendsen, I.A. and Haller, M., 1998. Numerical modelling of nearshore circulation on a barred beach with rip channels. In Proceedings 26th Coastal Engineering Conference, ASCE, 1: 801-814, Copenhagen.

Haller, M.C., Dalrymple, R.A. and Svendsen, I.A., 1997. Rip channels and nearshore circulation: Experiments. In Proceedings of the 3rd International Symposium on Ocean Wave Measurement and Analysis, ASCE, pp. 750-764.

Holthuijsen, L.H., Booij, N. and Ris, R.C., 1993. A spectral wave model for the coastal zone. Proceedings of the 2nd International Symposium on Ocean Wave Measurement and Analysis, New Orleans, pp. 630–641.

Lesser, G. R., Roelvink, J.A., van Kester, J. and Stelling, G. S., 2004. Development and validation of a three-dimensional morphological model. Coastal Engineering 51, 883-915.

Longuet-Higgins, M.S. and Stewart., R.W., 1964. Radiation stress in water waves: A physical discussion with applications. Deep Sea Research, 11(4): 529-563.

Reniers, A.J.H.M., Roelvink, J.A. and Thornton, E.B., 2004. Morphodynamic modelling of an embayed beach under wave group forcing. Journal of Geophysical research, Vol. 109, C01030

Rijkswaterstaat/RIKZ, 2002. Evaluation of shoreface nourishments in South-Holland, Interim Report. RIKZ/OS/2002.109x, The Haque, The Netherlands.

Roelvink, J.A. and Walstra, D.J.R., 2004. Keeping it simple by using complex models. 6th International Conference on Hydroscience and Engeneering (ICHE-2004), Brisbane Australia.

Roelvink, J.A., Reniers, A.J.H.M., Walstra, D.J.R. and van Ormondt, M, 2005. Shoreface nourishments: humps or bars? 5th International Conference on Coastal Dynamics 2005, Barcelona.

Roelse, P., 2002. Water en zand in balans. Evaluatie zandsuppleties na 1990; een morfologische beschouwing. RIKZ/2002.003

Spanhoff, R., Biegel, E. J., van de Graaff, J. and Hoekstra, P., 1997. Shoreface Nourishment at Terschelling, the Netherlands: Feeder Berm or Breaker Berm? In: Thornton, E. B. (Ed.), Proc. 3rd International Conference on Coastal Dynamics ’97. ASCE, New York, pp. 863–872.

Spanhoff, R., Biegel, E.J., Burger, M. and Dunsbergen, D.W., 2003. Shoreface nourishments in The Netherlands. Coastal Sediments, Florida, USA

Sun, B. 2004. Validation of hydrodynamic and morphodynamic modelling on a shoreface nourishment at Egmond. The Netherlands. IHE Mscthesis, Delft Hydraulics report Z3624.

T.A.W., 1995. Basisrapport zandige kust, behorende bij de leidraad zandige kust. Juli 1995

van Duin, M.J.P., 2002. Evaluation of the Egmond shoreface nourishment, Part 3: Validation morphological modelling Delft3D-MOR. WL | Delft Hydraulics report Z3054/Z3148, June 2002.

van Duin, M.J.P., Wiersma, N.R., Walstra, D.J.R., Van Rijn, L.C. and Stive, M.J.F., 2004. Nourishing the shoreface: observations and hindcasting of the Egmond case, The Netherlands. Coastal Engineering 51, 813-837

van Rijn, L.C., 1998. Principles of coastal morphology. Aqua Publications, Emmeloord, The Netherlands

van Rijn, L.C., 2004. Analysis and modelling of shoreface nourishments. WL | Delft Hydraulics report Z3748.20, September 2004.

Walstra, D.J.R., Roelvink, J.A. and Groeneweg, J., 2000. Calculation of wave-driven currents in a 3D mean flow model. Edge, B. Coastal Engineering vol. 2. ASCE, New York, pp. 1050– 1063.

Walstra, D.J.R., Van Ormondt, M. and Roelvink, J.A., 2004. Shoreface nourishment scenarios. WL | Delft Hydraulics report Z3748.21, November 2004.

Westlake, S.J., 1995. NOURTEC. Behaviour of a shoreface nourishment, Terschelling, The Netherlands. Master thesis IHE, Delft, The Netherlands.

WL | Delft Hydraulics. 2003a (March). DELFT3D-FLOW, User manual. Version 3.10, Delft, The Netherlands.

Wright, L.D. and Short, A.D., 1984. Morphodynamic variability of surf zones and beaches: a synthesis. Marine Geology 56, 93–118.

A Momentary coastline

In 1990, Dutch government adopted a policy of "Dynamic Preservation" to prevent structural erosion of the coast. The 1990 shoreline was adopted as the Basal CoastLine (BCL), recession beyond this line is not allowed. The main design objective of shoreface nourishment is to improve shoreline stability and prevent the shoreline from (structural) erosion. Every random moment in time The Momentary CoastLine (MCL) in a cross-shore profile can be determined by a volumetric computation. The Momentary Coastlines for the 10 previous years form a tendency (TCL) on which it can be checked whether the coastline fulfils the condition in future and if maintenance is needed.

Structural erosion is a matter when the average low water is shifting shoreward during a period of 10 years. To decide whether the coast should be maintained the following method has been developed. To prevent that decision making is done on the hand of coincidences of profile fluctuations a coast line is defined, representing the average position of the profile. Figure 1 shows how the Momentary Coast Line (MCL) is defined.

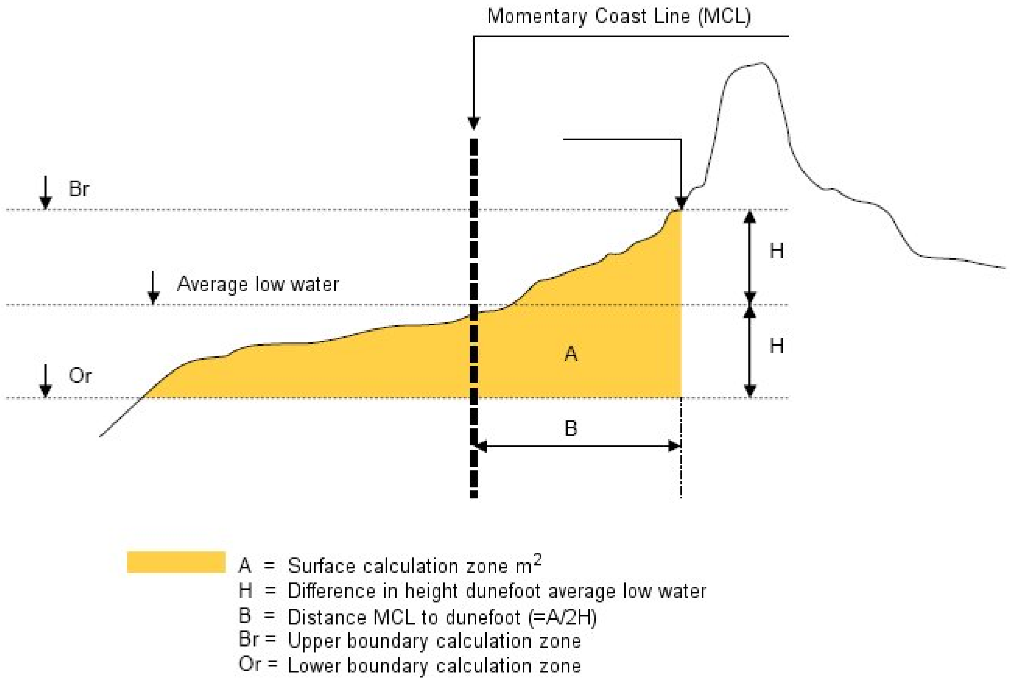


Figure 1 Momentary Coast Line calculation (Roelse, 2002)

Policy is to maintain the shoreline seaward of the BCL (Basal Coast Line), being the position of the coastline on 01-01-1990. By extrapolating a number of momentary coastlines the need for nourishing of the profile can be determined. Figure 2 shows how the Trend Coast Line has been changed by executing nourishments.

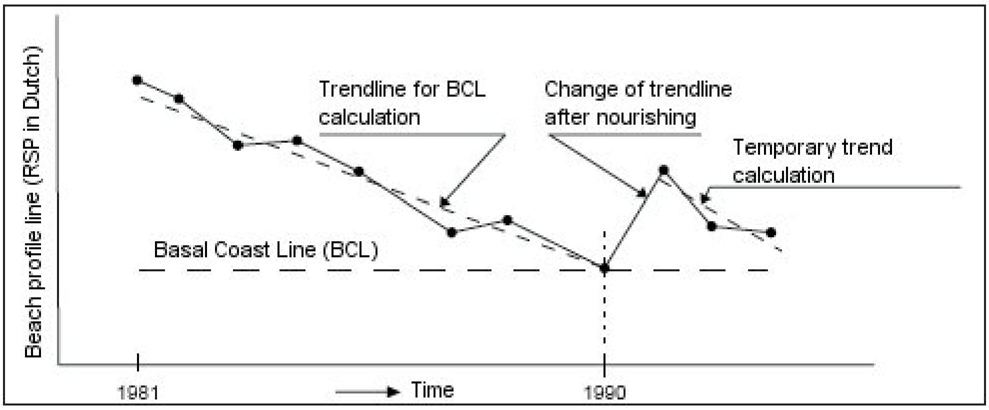


Figure 2 Trend Coast line (TCL) definition in combination with Basal Coast Line (Roelse, 2002)

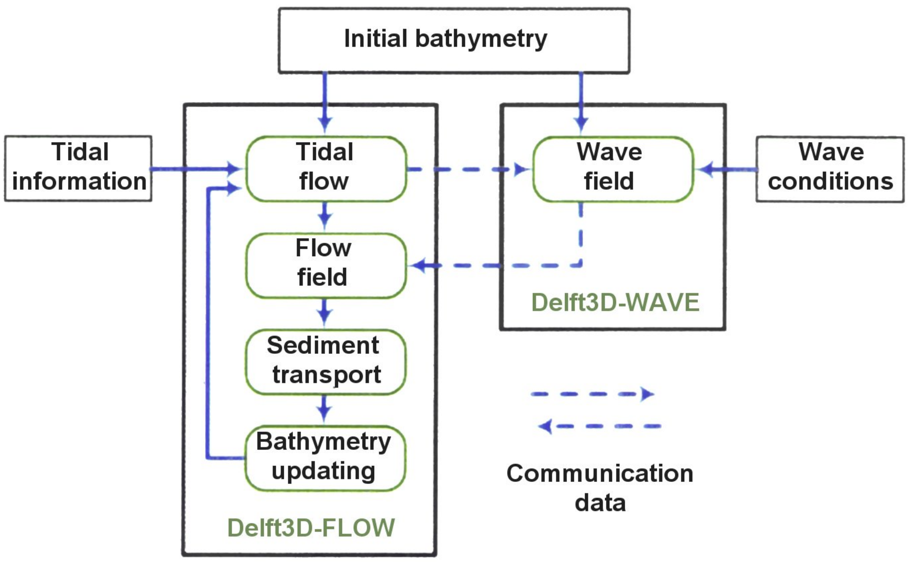
B Model setup

B.1 The Delft 3D model

The Delft3D model is an example of a process-based model. Process-related models are based on the detailed description of relevant processes as waves, tide, currents and sediment transport. Interaction of these processes cause a varying flow field and bed level changes which are computed in Delft3D. In coastal applications two types of process based models can be distinguished: area models and profile models.

In profile models only cross-shore components of relevant processes are included, longshore components are assumed to be constant. Examples of these are 1DH modelling in which velocity is averaged over the total depth and 2DV for which the depth is divided in layers for numeric computation. Area models can be two or three dimensional (2DH, 3D) and include wave- and tide-driven currents and sediment transport which can differ in cross shore and longshore distances. In both the profile and the area models, bed level changes follow from a numerical solution of the mass conservation balance.

Delft3D has been designed to compute hydrodynamic and morphodynamic changes in time by combining all related processes. The program consists of several integrated modules used for modelling currents, waves, sediment transport and bed level changes. The Delft3D version used for this study uses Delft3D-FLOW as the heart of the framework of modules. The FLOW-module performs the hydrodynamic computations and simultaneously ("online") calculates waves, transport of sediments and an update of the bathymetry. The figure shows a schematisation of the online Delft3D approach used. Exchange of data is performed by writing a communication file after running the wave and flow computations.



Schematisation of the online updating of the Delft3D FLOW-module (Sun, 2004)

The FLOW-module provides the hydrodynamic basis for many cases in coastal environments. In Lesser *et al.* (2004) a description is given of the online version of the

FLOW-module and its applications. The following section will give a short introduction, for a detailed information see references (Lesser *et al.*, 2004 and WL | Delft Hydraulics, 2003).

FLOW-Module

The FLOW module is a hydrodynamic flow simulation program that simulates transport phenomena and solves the unsteady shallow-water equations in 2DH (depth-averaged) or 3D. In the module phenomena as tide, wind and wave driven flows, stratified and density flows are included in situations where bottom level, water level and velocity field change significantly during a flow simulation. Three-dimensional modelling is based on a number of layers which are constant over the computational grid, meaning that the size of each layer is proportional to the local depth. In each layer the same conservation equations are solved as in the 2DH model. Recent modifications in the FLOW module included three dimensional wave effects as wave-induced mass flux, wave-induced turbulence, streaming and forcing due to wave breaking (Walstra *et al.*, 2000).

WAVE-Module

This study makes use of the SWAN (Simulating WAves Nearshore, Holthuijsen *et al.*, 1993) model which is a third-generation model with the biggest advantage that it makes use of the same grid as the FLOW-module. The mean wave directions are computed by the wave model SWAN after which the energy associated with the waves propagating shoreward is computed. A new wave and roller module is describing wave propagation and breaking, operating on timescale of wave groups and is coupled to a depth averaged non linear flow model to predict the time dependent infragravity flow field (Reniers *et al.*, 2004)

Sediment-Online

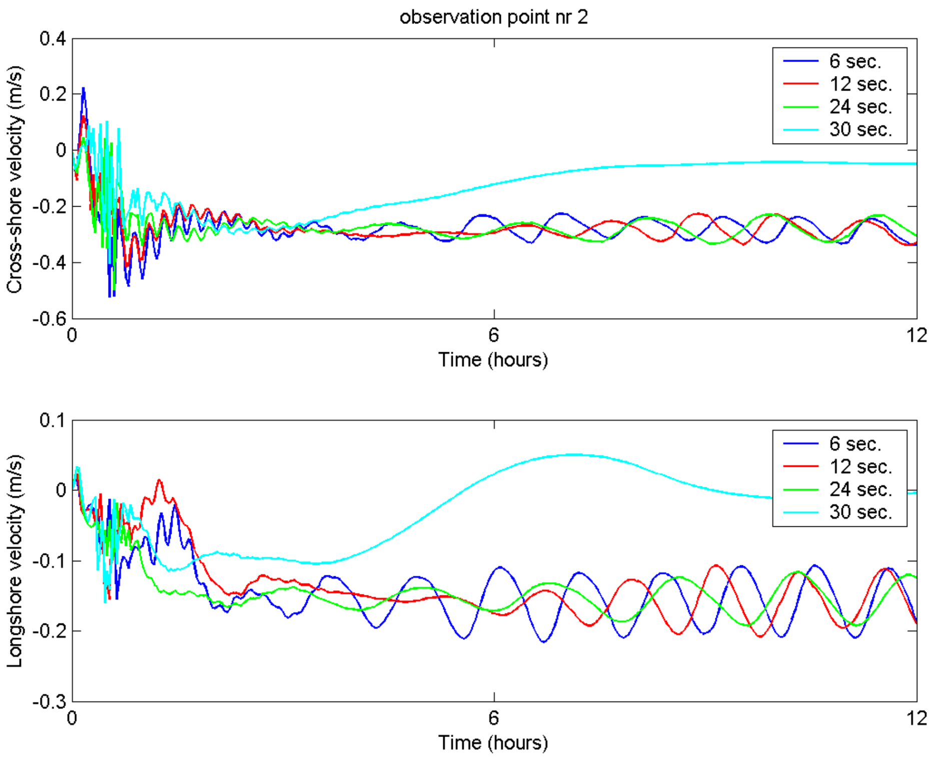
For sediment transport a new approach has been implemented. Instead of using the modules Delft3D-SED and -MOR the sediment online version continuously updates transport of sediments and therefore is possible to change the bed-level and give feedback to the hydrodynamics. For the transport of sediments two types of sediment transport are computed. Over the entire water column the suspended sediment is computed and for a reference height above the bottom the bedload transport is computed. A correction vector is introduced to prevent double counting.

The main advantages of using the online approach of Delft3D-FLOW are summarized (Lesser at al., 2000)

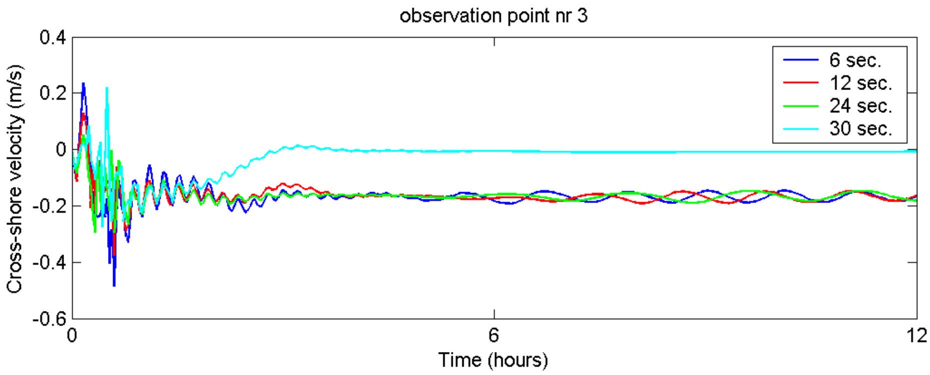
- Three-dimensional hydrodynamic processes and the adaptation of non-equilibrium sediment concentration profiles are automatically accounted for in the suspended sediment calculations;
- The density effects of sediment in suspension (which may cause density currents and/or turbulence damping) are automatically included in the hydrodynamic calculations;
- Changes in bathymetry can be immediately fed back to the hydrodynamic calculations;
- Sediment transport and morphological simulations are simple to perform and do not require a large data file to communicate results between the hydrodynamic, sediment transport, and bottom updating modules.

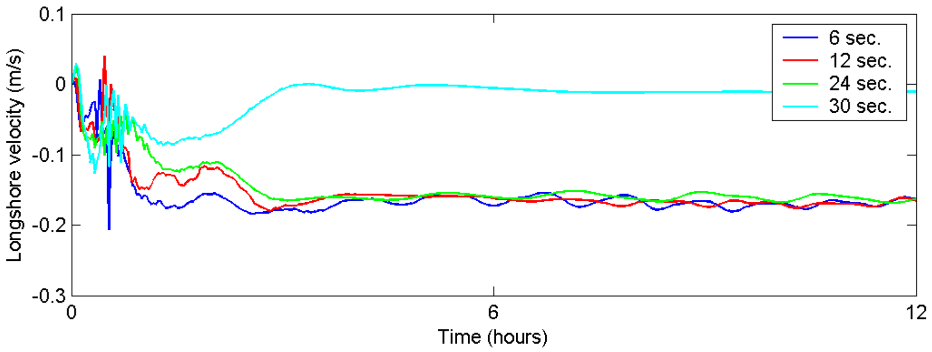
Morphodynamic development time scales are significantly bigger than those of hydrodynamic time scales. The morphological acceleration factor is therefore used so only for a fraction of the duration the hydrodynamic simulations are required. In this way the speed of changes in the morphology is scaled up to a rate where it begins to have a significant impact on the hydrodynamics and the computational time can be reduced. More detailed descriptions of the model formulations are dealt with hereafter. During the coarse of this study model parameters and input will change, the overall schematisations will be discussed in this chapter.

B.2 Time step analysis



Velocities at observation point number 2, in the middle of a gap between two humps





Velocities at observation point number 3, upstream of the humps

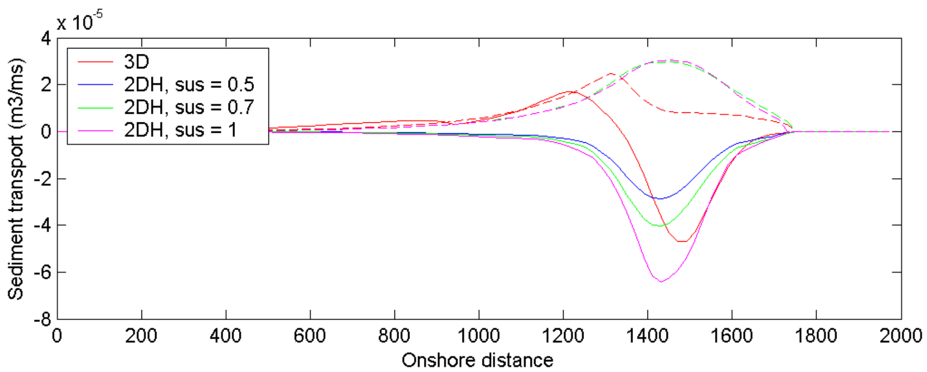
B.3 Transport parameters

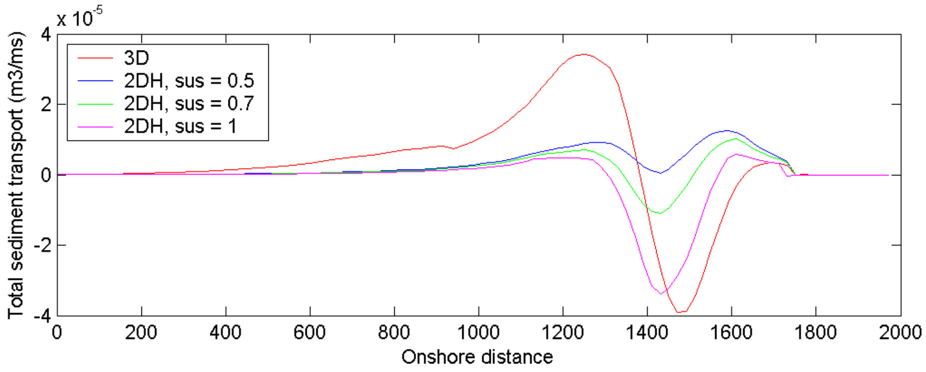
For determining of the parameters for the transports computed by TRANSPOR2004 the parameters used for Egmond (Walstra, 2004) were used. These parameters fitted best for the local situation and are used as a reference for the current study. The transport properties for the undisturbed, plane profile model as dealt with in the report gives results which will be used as a reference for the 2DH model.

This appendix shows results after varying the parameters: SUS, BED, SUSW and BEDW. These parameters describe the relative contribution of waves and flow to the suspended and bed load transport and as a result the total transport. Mentioned parameters will be varied to get some insight in their influences and a final setting, describing the transports the best, will be the result. In all cases the red lines refer to the 3D profile model, which is the reference model for the calibration of the parameters. The dotted lines represent the bed load transports, the others are the suspended load.

Parameter variation SUS

The figures below show how the SUS-parameter has only influence on the suspended load. In these cases the BED, SUSW and BEDW were kept on respectively 1, 0,2 and 1 and are assumed to give representative values. A value of 0,8 describes the magnitude of the peak value for suspended load best.

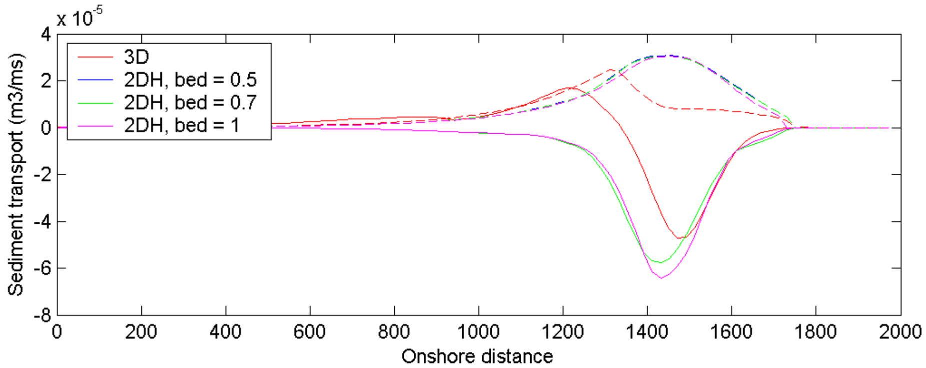


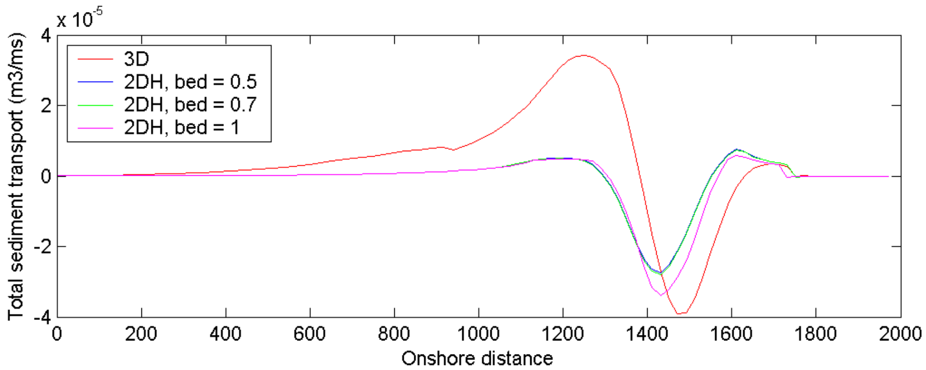


As the total transports show the offshore peak shows similar magnitudes but is located more offshore and onshore peaks are less good.

Parameter variation BED

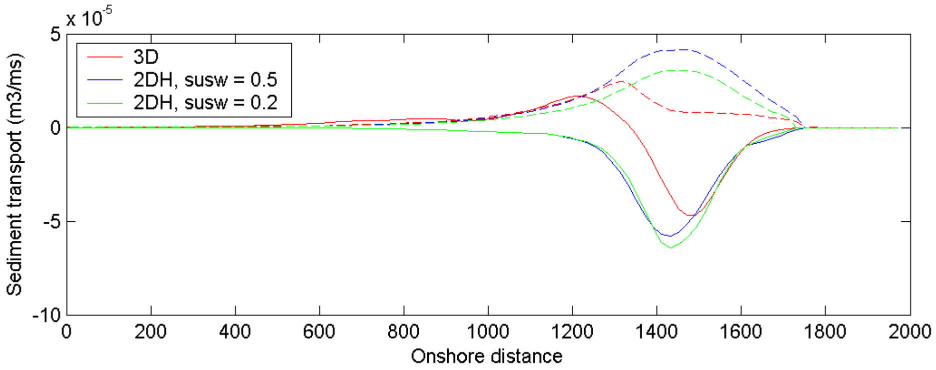
The BED-parameter has little influence on the suspended load transport. As for the bed load transport, the parameter does not have a significant impact. Though, a value of 0.7 in combination with the 0,8 for the SUS parameter gives good results.

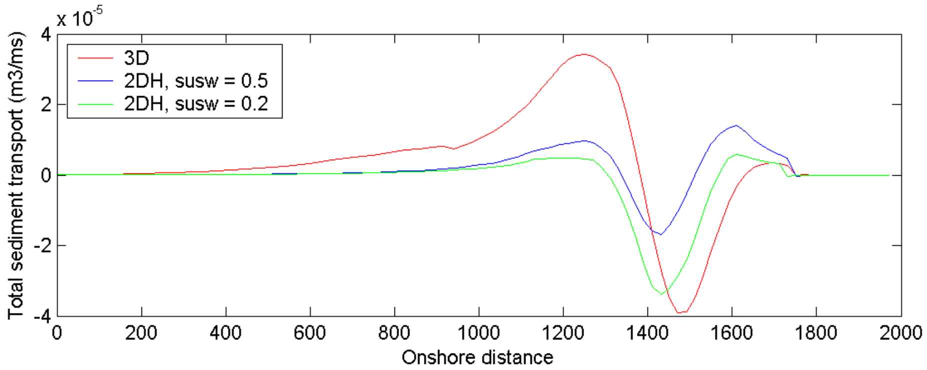




Parameter variation SUSW

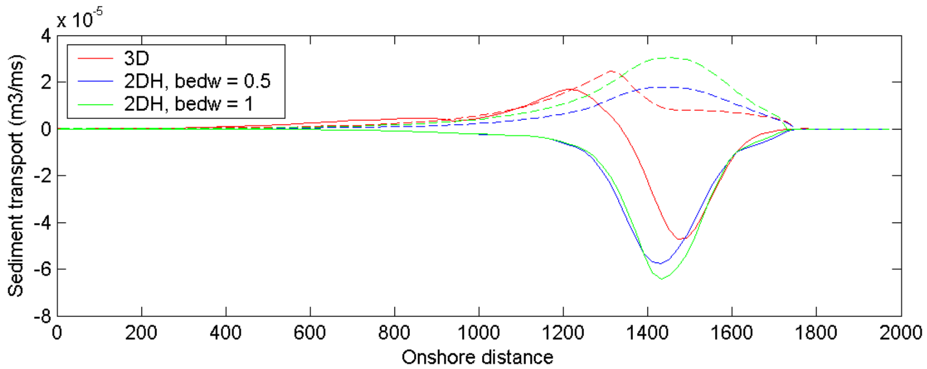
The SUSW-parameter is the parameter describing the contribution of the transport due to waves. This parameter has not only influence on the suspended load but significant impact on bed load as well. The value of 0.2 shows a good description of the bed load transport without disturbing the suspended load and bringing the total transport into balance so the shoreface will be more or less in its equilibrium. This means that the total onshore and offshore transport is similar. Gradients in these transports will cause sedimentation and erosion. These will not be similar but assumed is that the behaviour of the nourished sections will be comparable with the 3-dimensional situation.

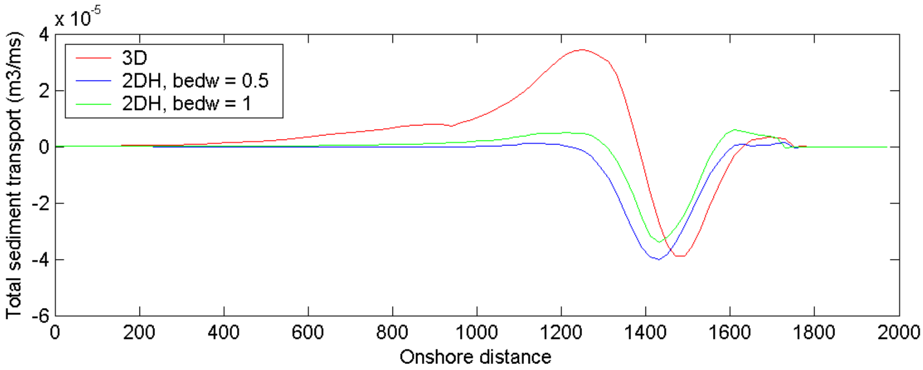




Parameter variation BEDW

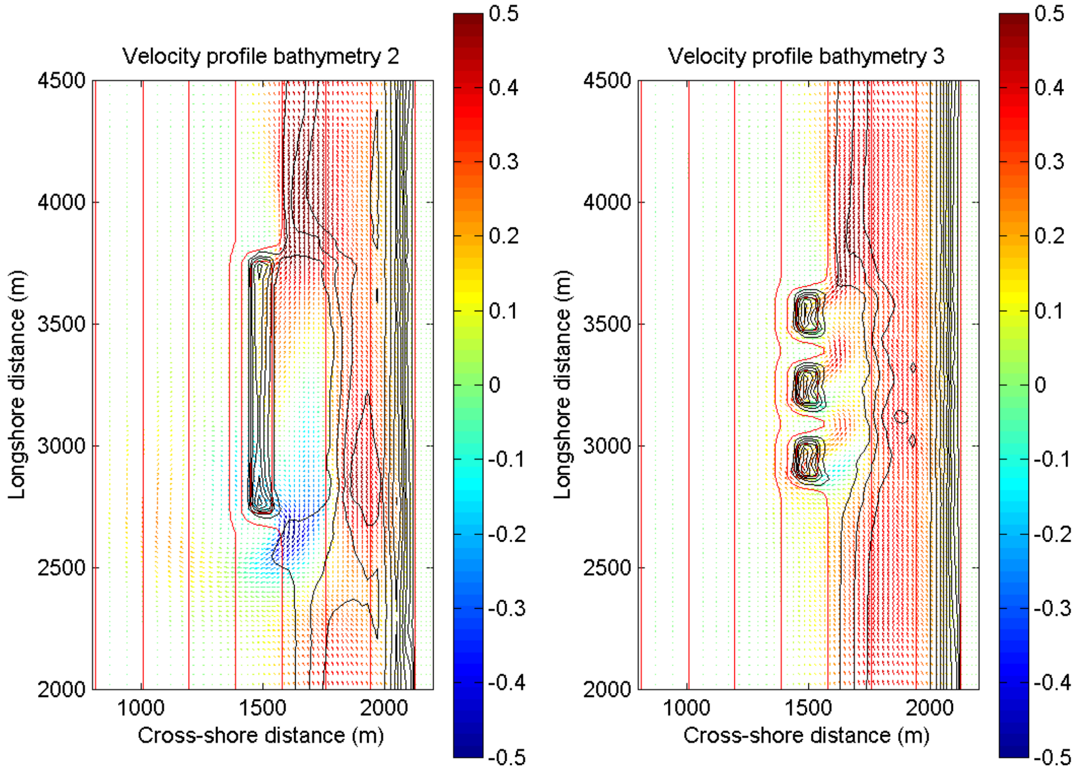
Leaving the BEDW-parameter on its default of 1, in combination with the value of 0.2 for SUSW shows a good representation of the bed load transport.



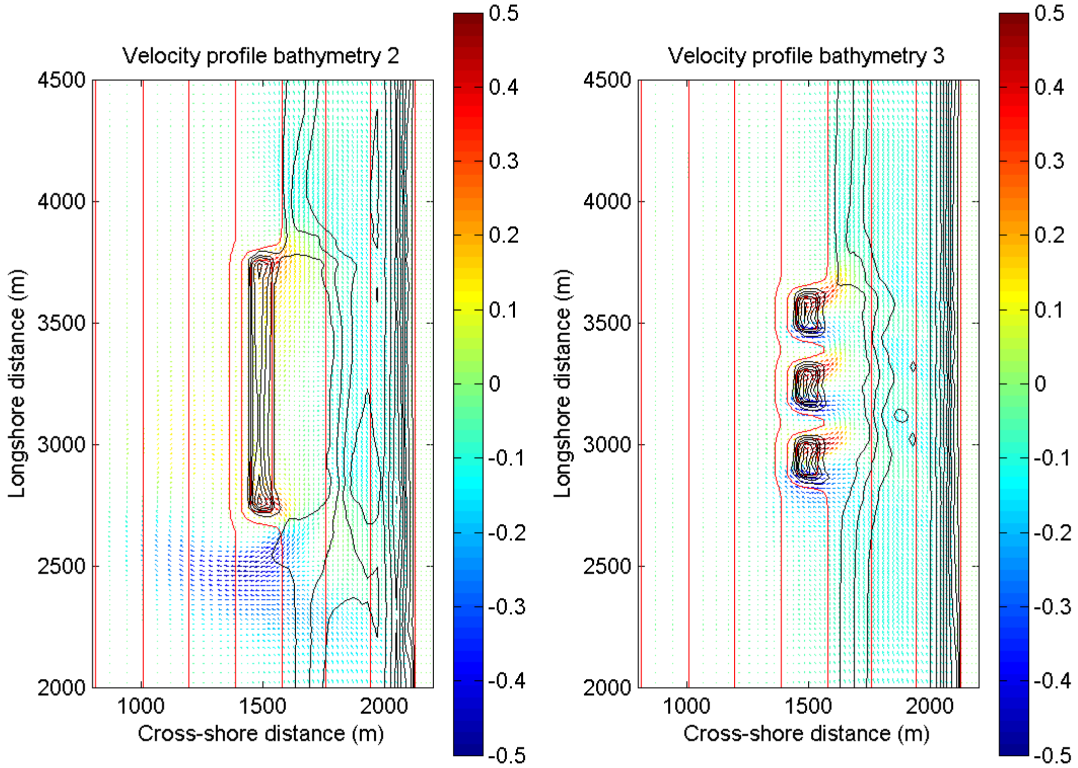

x 10^-5
Total sediment transport (m3/ms)
Onshore distance
3D
2DH, bedw = 0.5
2DH, bedw = 1
4
2
0
-2
-4
-6
0
200
400
600
800
1000
1200
1400
1600
1800
2000

C Hydrodynamic analysis

C.1 Vector plots bar and hump scenarios

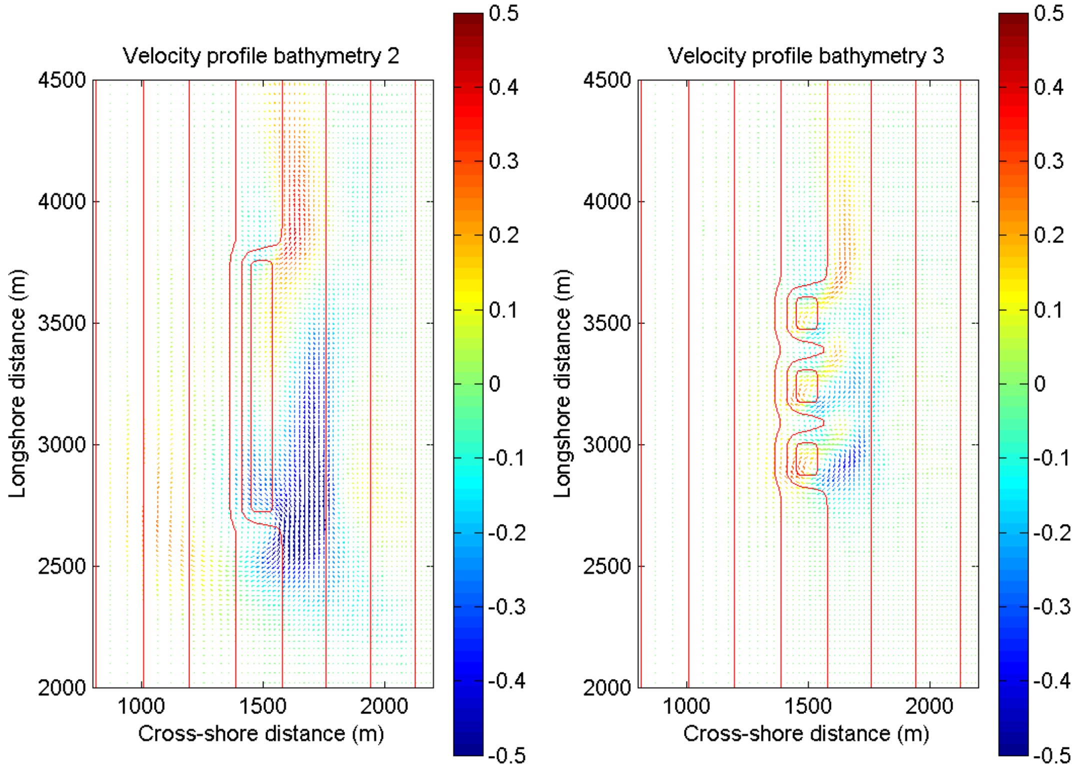


Longshore components of velocity coloured for left, the bar nourishing and right the hump nourishing

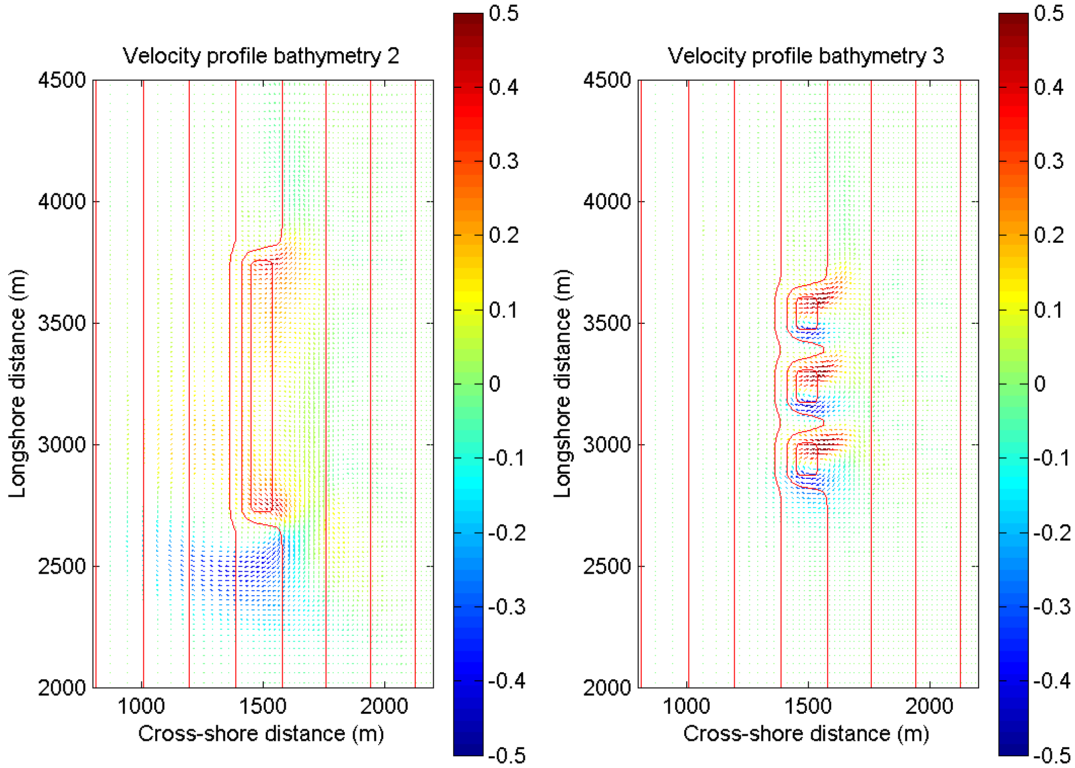


Cross-shore components of velocity coloured for left, the bar nourishing and right the hump nourishing

C.2 Net result for the velocity vectors

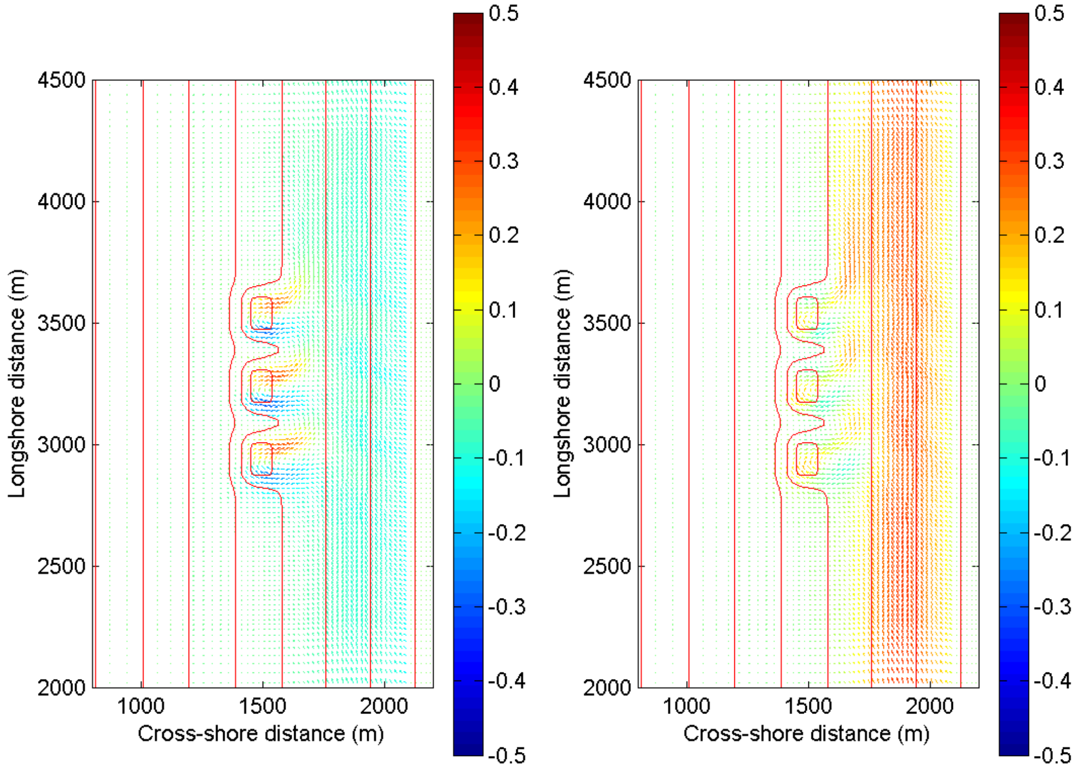


Net longshore components of velocity coloured for left, the bar nourishing and right the hump nourishing

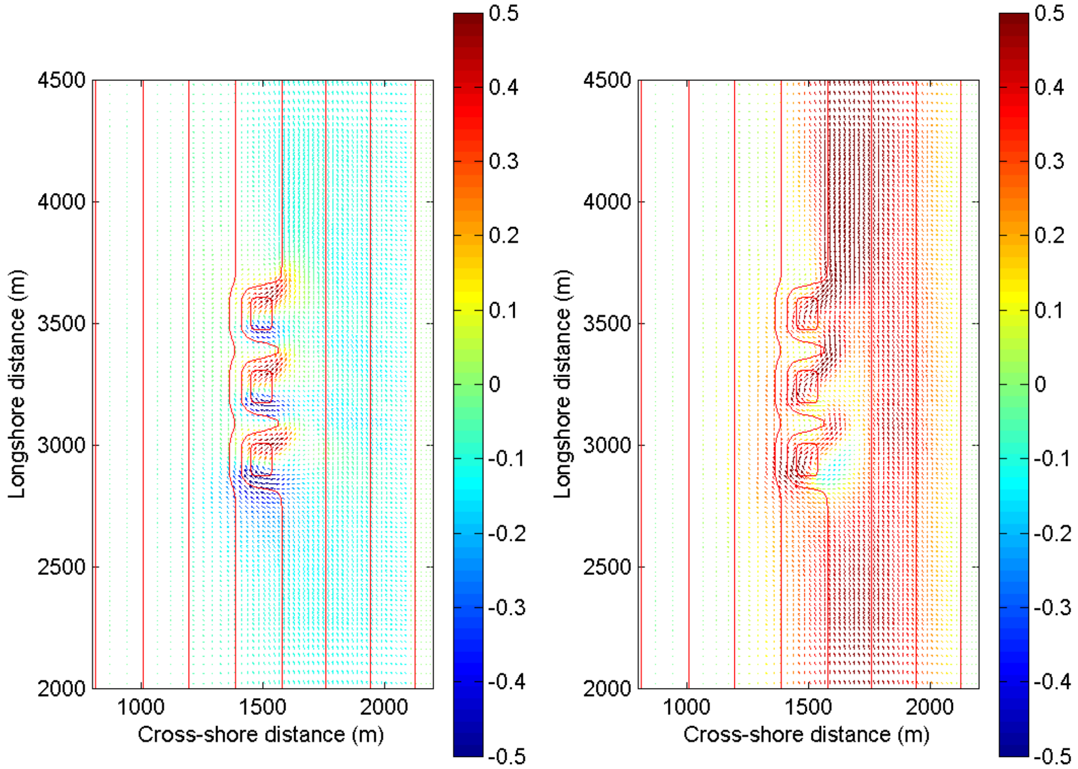


Net cross-shore components of velocity coloured for left, the bar nourishing and right the hump nourishing

C.3 Velocity vectors for different wave heights

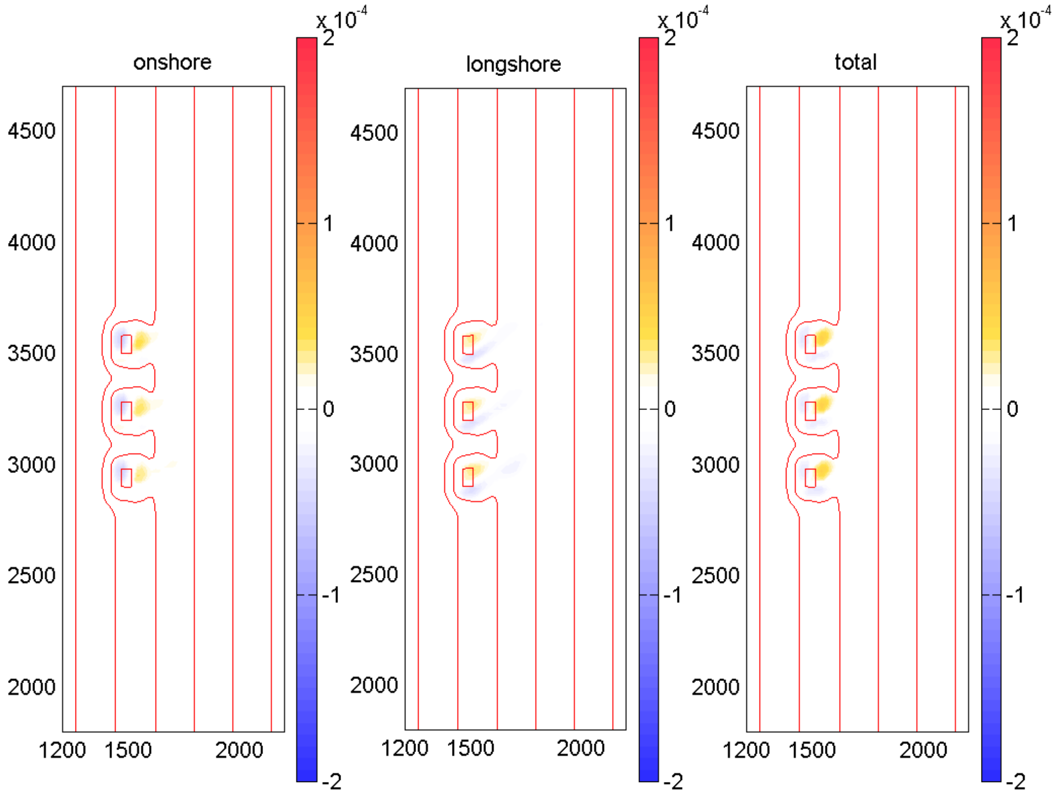


Wave height of 1.5 meter for humplike nourishing, left cross-shore velocities, right longshore velocities

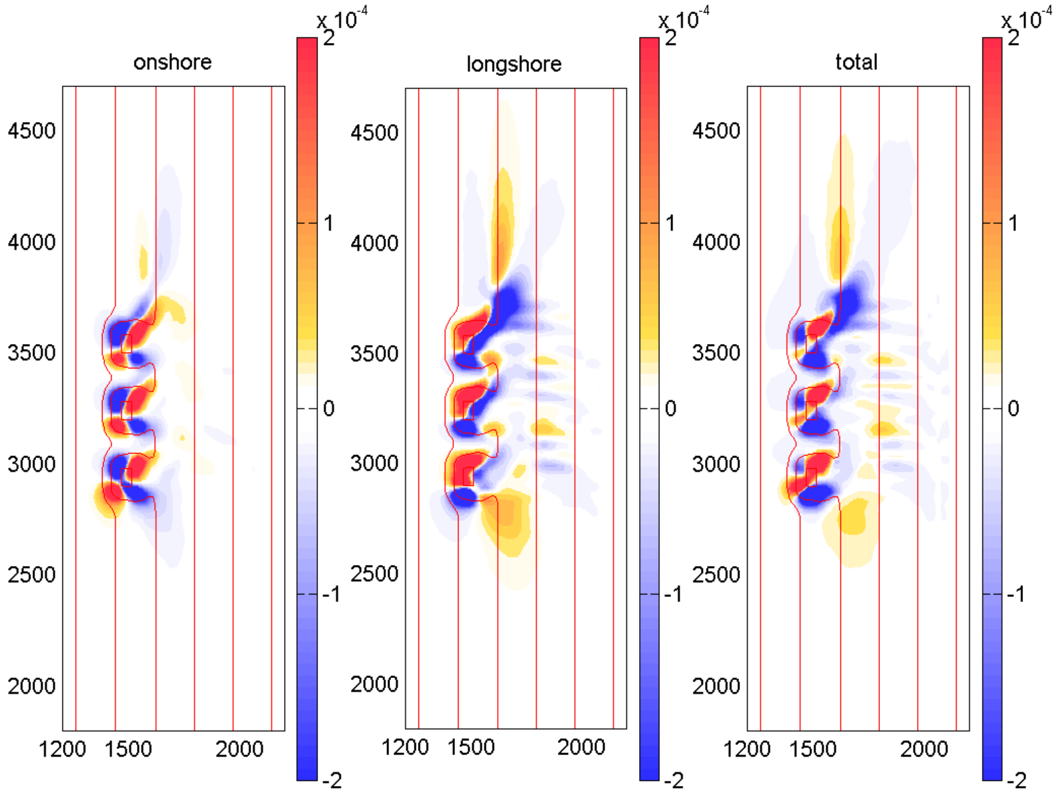


Wave height of 2.5 meter for humplike nourishing, left cross-shore velocities, right longshore velocities

C.4 Sedimentation erosion plots for different wave heights

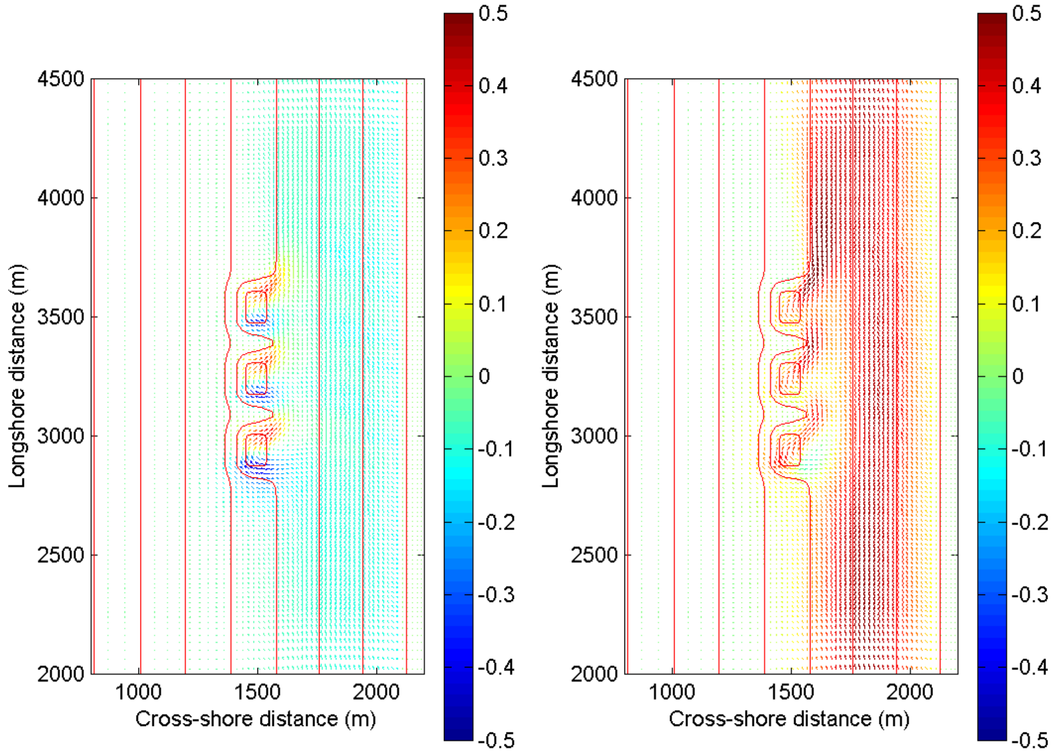


Initial sedimentation and erosion plots for the humplike nourishing for a wave height of 1.5 meter

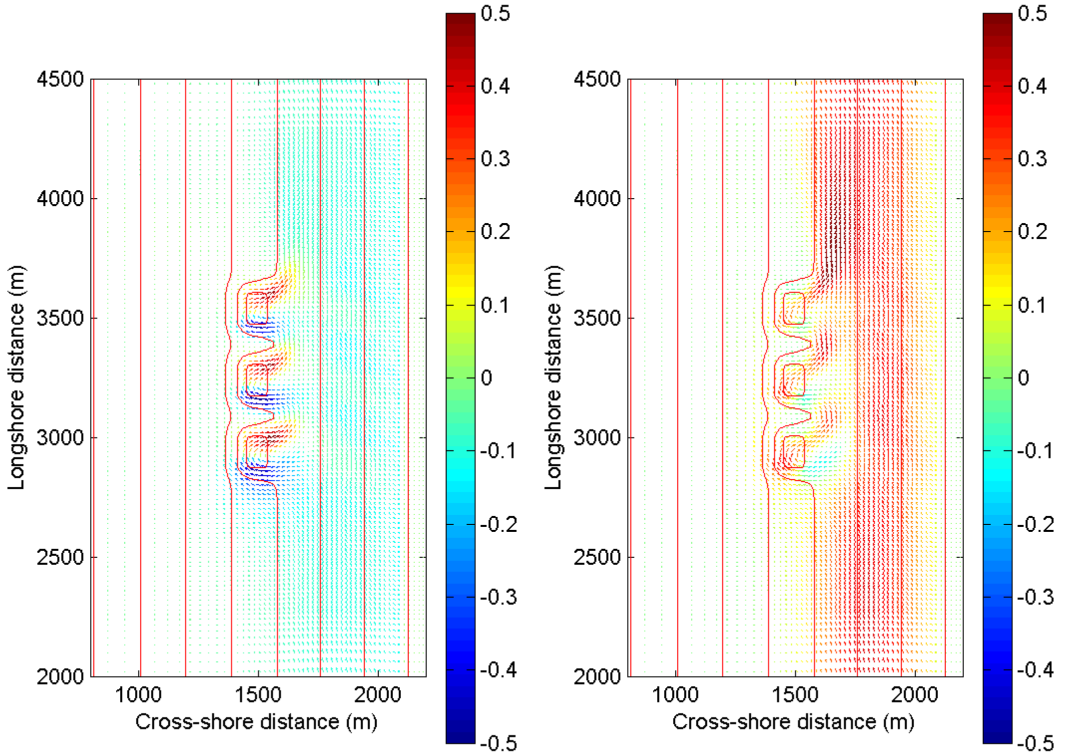


Initial sedimentation and erosion plots for the humplike nourishing for a wave height of 2.5 meter

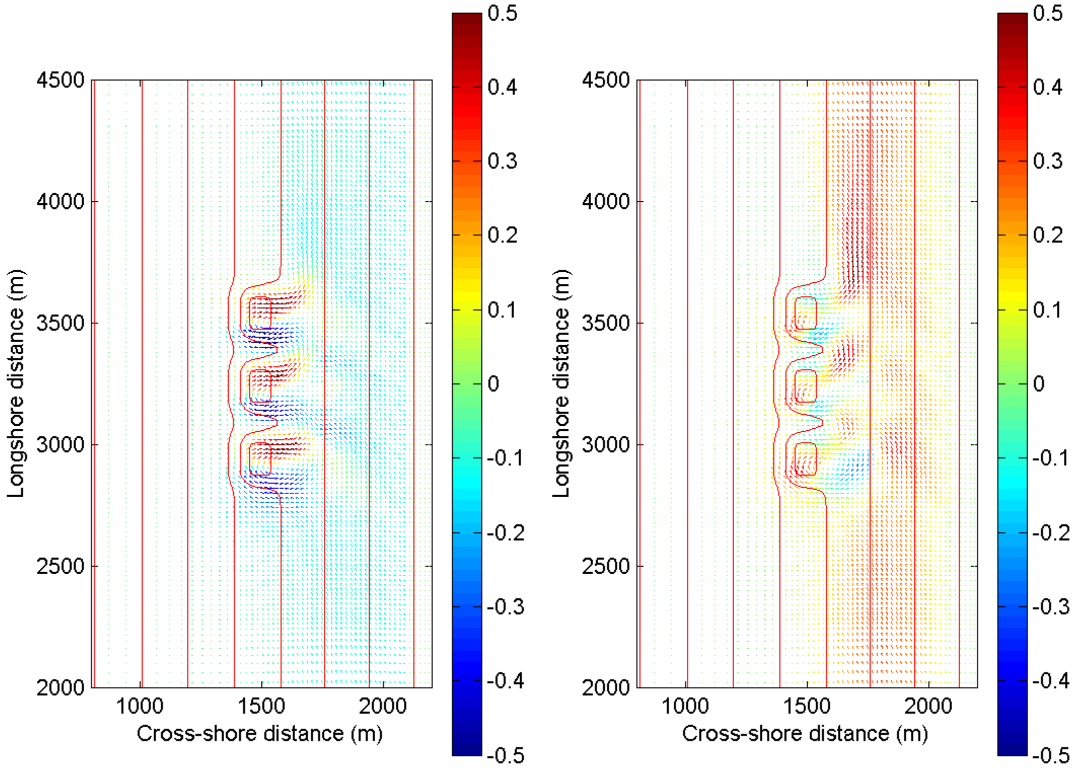
C.5 Velocity vectors for different approach angles



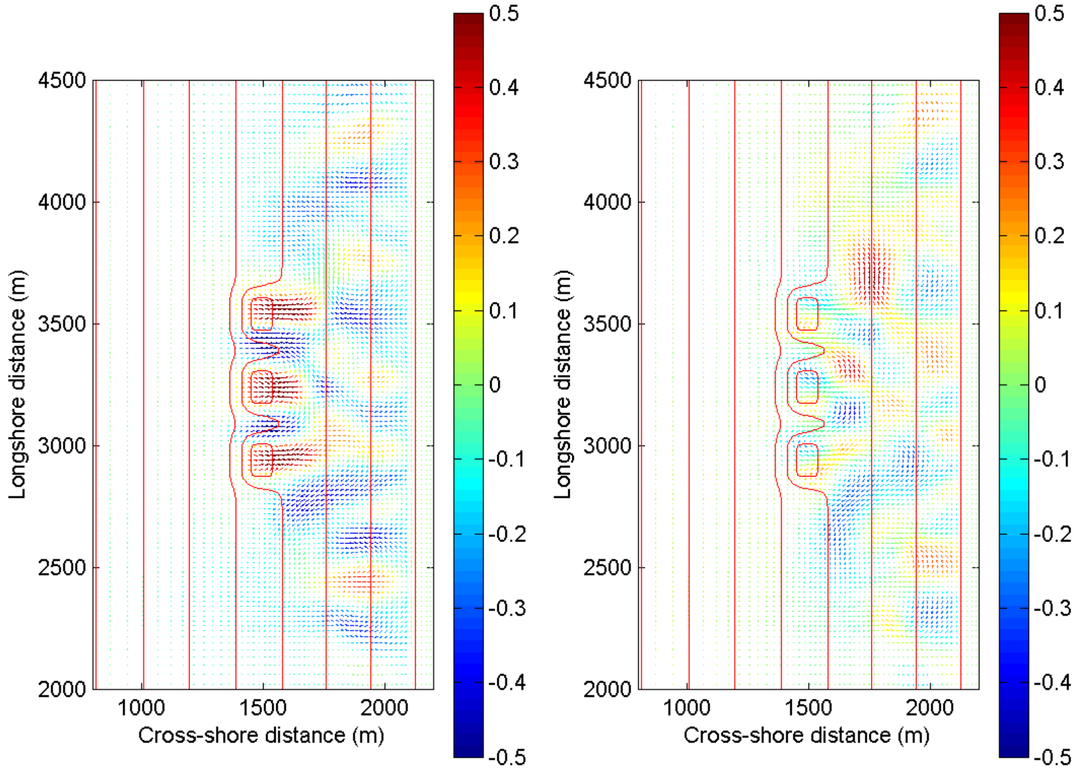
Wave approach angle of 240 deg for humplike nourishing, left cross-shore velocities, right longshore velocities



Wave approach angle of 250 deg for humplike nourishing, left cross-shore velocities, right longshore velocities

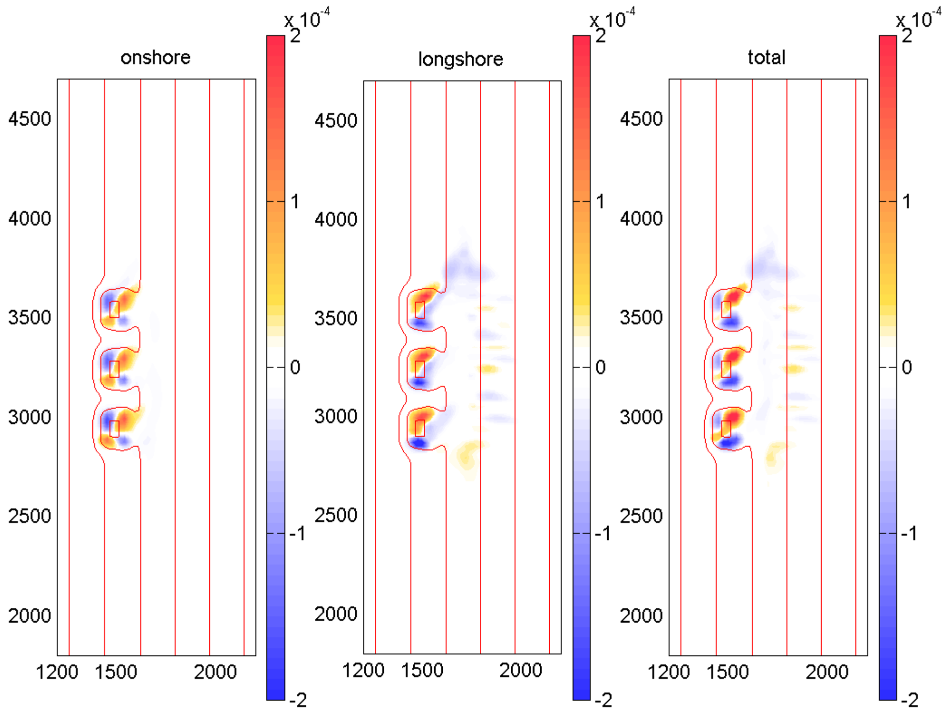


Wave approach angle of 260 deg for humplike nourishing, left cross-shore velocities, right longshore velocities

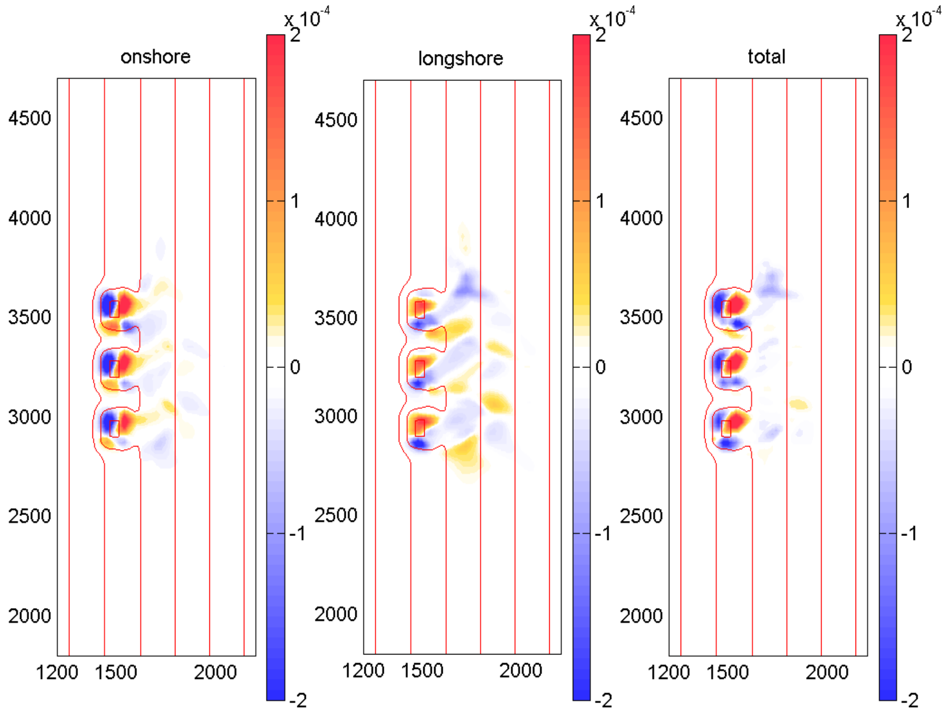


Wave approach angle of 270 deg for humplike nourishing, left cross-shore velocities, right longshore velocities

C.6 Sedimentation erosion plots for different approach angles

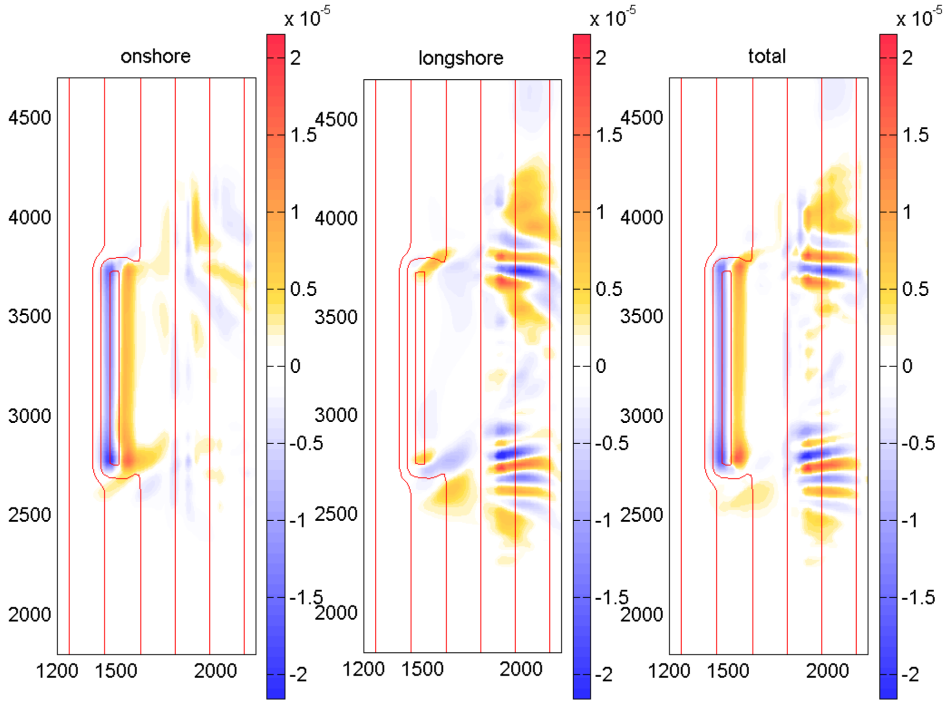


Initial sedimentation and erosion plots for the humplike nourishing for a wave approach angle of 240 degrees

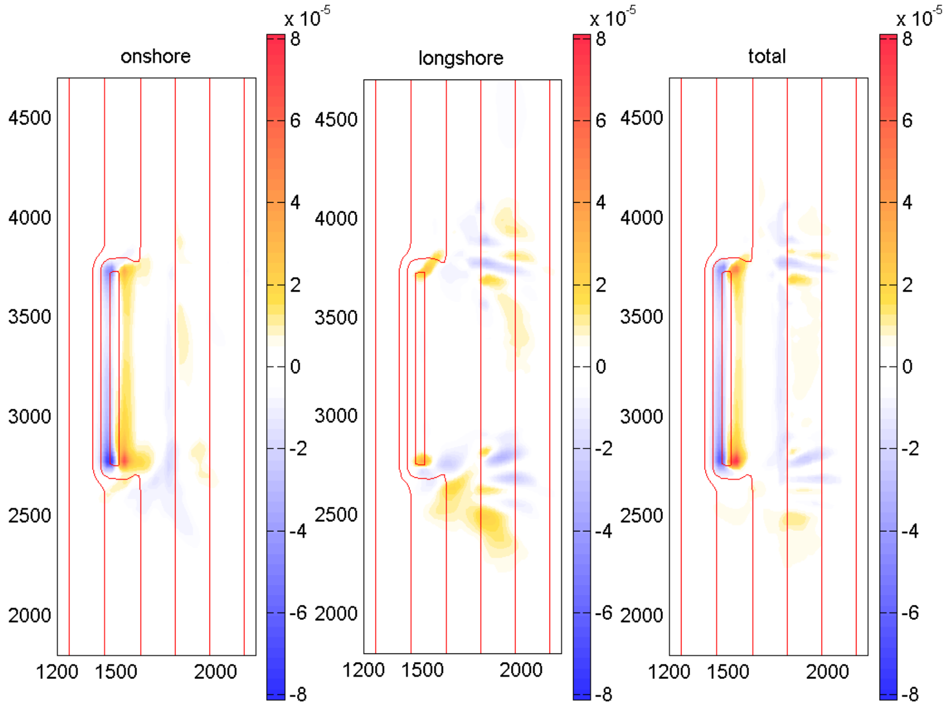


Initial sedimentation and erosion plots for the humplike nourishing for a wave approach angle of 260 degrees

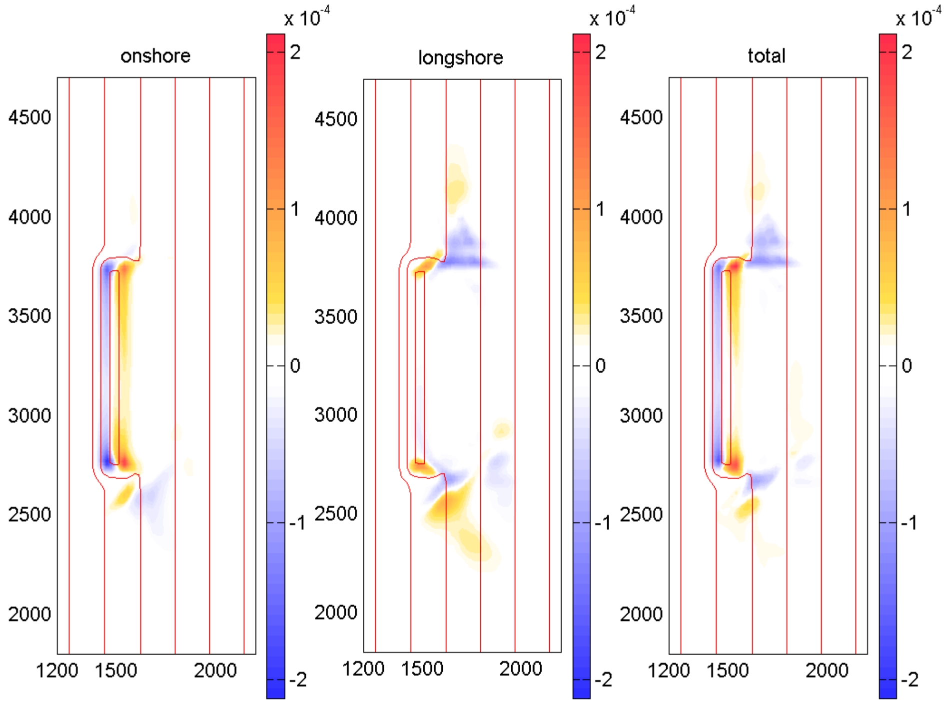
C.7 Sedimentation erosion plots for different water depths



Initial sedimentation and erosion plots for bar nourishing for a waterdepth of 5 meter



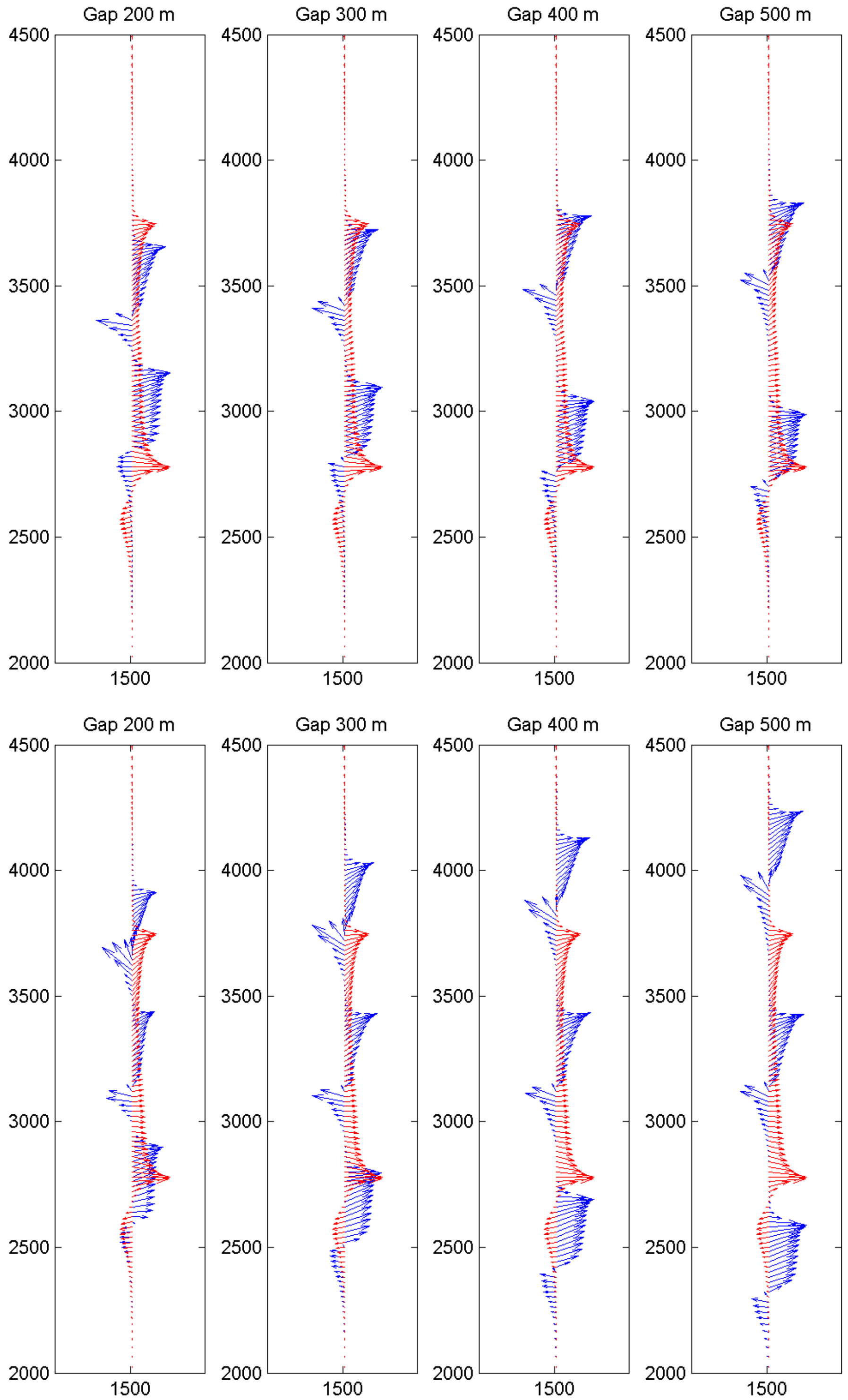
Initial sedimentation and erosion plots for bar nourishing for a waterdepth of 4 meter



Initial sedimentation and erosion plots for bar nourishing for a waterdepth of 3 meter

D Geometric analysis

D.1 2 humps versus 3 humps with 300 meter length



D.2 Practical example

Example

For a planned nourishment an amount of 1.000.000 m^3 sand is available. Two different objectives will be worked out:

a) Finding the scenario resulting in the biggest onshore gain of sediment, independent on the length covered by the executed nourishments;
b) Finding a scenario with maximum gain for a length of maximum 3000 meter.

Procedure a)

- A bar with a volume of 1.000.000 m^3 has a length of 2000 meter,

V/A = L, with A is 500 m^2, V is the available Volume and L is the nourished length

- Efficiency from figure 5-9
- Number of hump:

$$\text{number (round)} = \frac{available\ Volume(m^3)}{40.000(m^3)+humplength*500(m^2)}$$

- Volume is the number of humps multiplied with the volume per hump
- Gain is the efficiency multiplied with the nourished volume

Scenario length-gap	**Efficiency (10^{-4})**	**Number**	**Volume (m^3)**	**Total length (m)**	**Gain (m3/hour)**
bar	1,34	1	1.000.000	2000	134
200-300	1,31	7	980.000	3500	128
200-500	1,40	7	980.000	4900	137
300-300	1,37	5	933.000	3000	127
300-500	1,58	5	933.000	4000	147

The highest efficiency from figure 5-9 is $1{,}58.10^{-4}$ for a scenario with 500 gap width and hump lengths of 300 meter. For this variant 5 humps can be executed with a total volume of 933.000 m^3. Some other scenarios were described in the table for better comparing of the results.

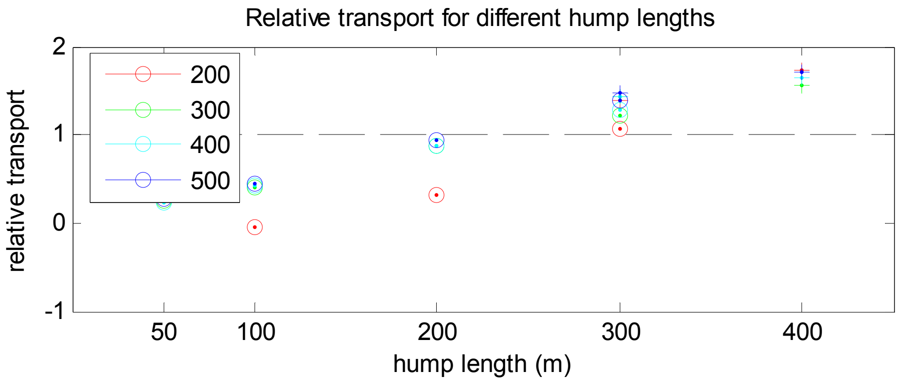
Procedure b)

The showed results led to executable scenarios covering more than 3000 (m) length. Keeping the total nourished length shorter than this value leads to bar nourishing. Figure 5-12 shows that the nearest value to the bar nourishing is for a scenario with 100 meter length and 300 meter gap width. In potential the 200 meter gap width would give more gain. Problem with this procedure is that it does not take care of the influence of the volumes. The table below shows that these nourishments do not make optimal use of the amount sand.

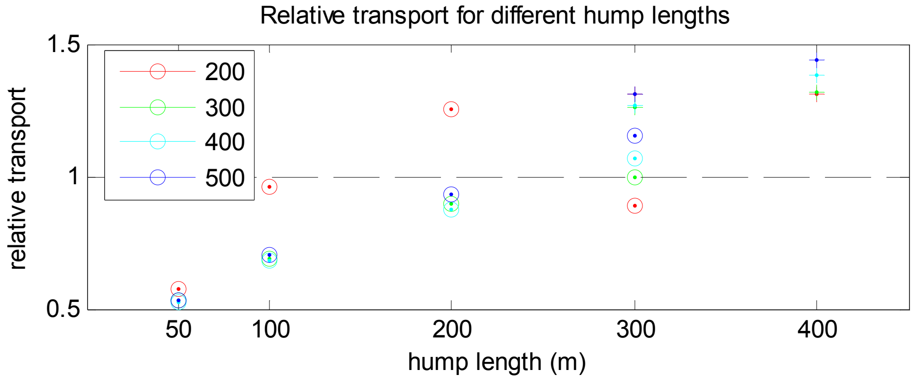
Scenario length-gap	Efficiency (10^{-4})	Number	Volume (m^3)	Total length (m)	Gain (m^3)
bar	1,34	1	1.000.000	2000	134
50-300	1.10	8	560.000	2800	61.6
100-300	1,26	7	630.000	2800	79
200-300	1.31	6	840.000	3000	110

D.3 Sensitivity on cross-shore location for evaluating

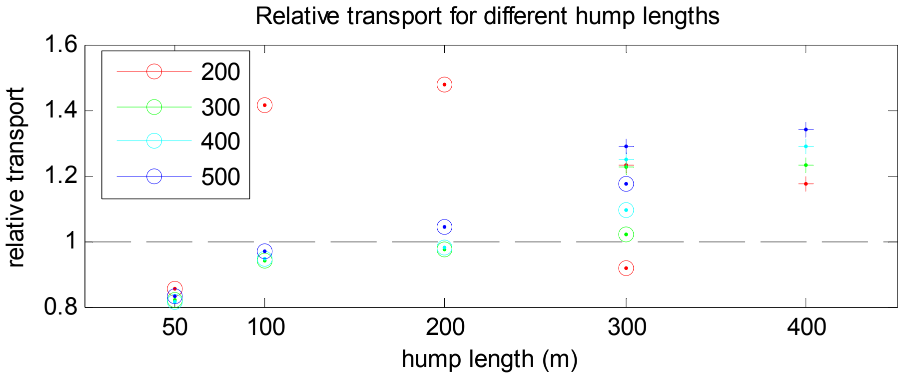
X = 1420 meter, offshore of the crest



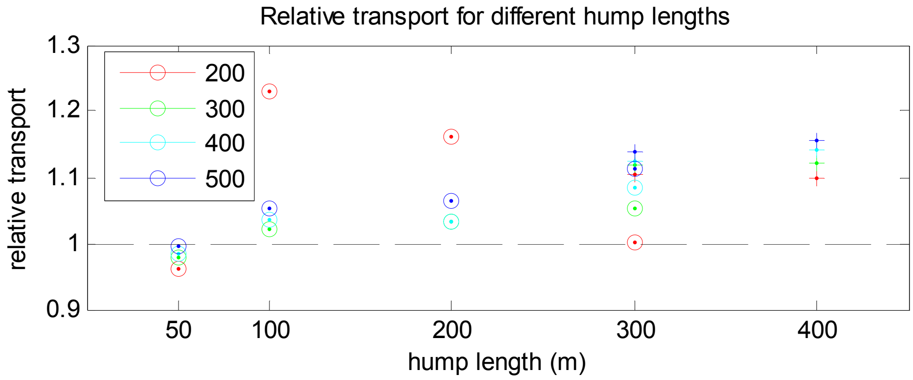
X = 1460 meter, offshore of the crest



X = 1500 meter, on the middle of the crest

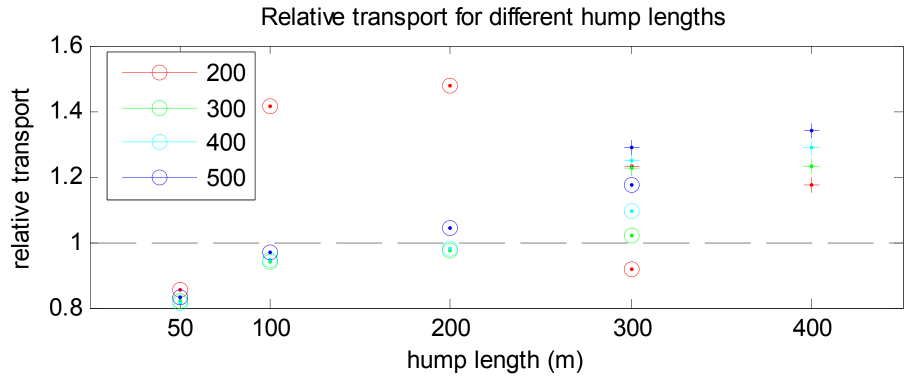


X = 1540 meter, onshore of the crest

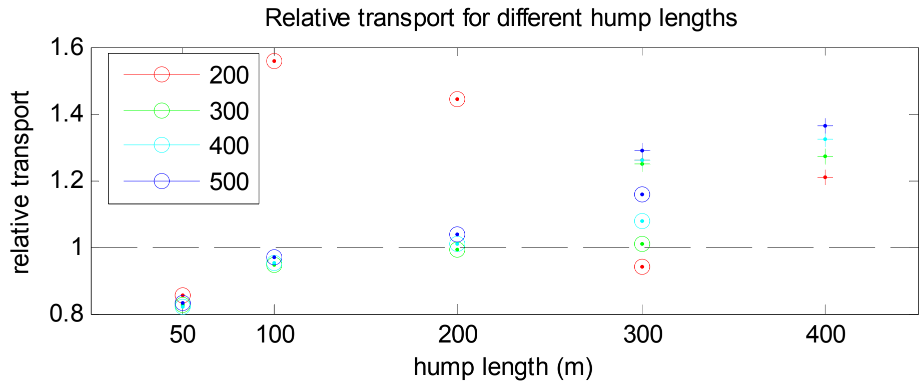


D.4 Sensitivity on time dependency

t = 12 hours

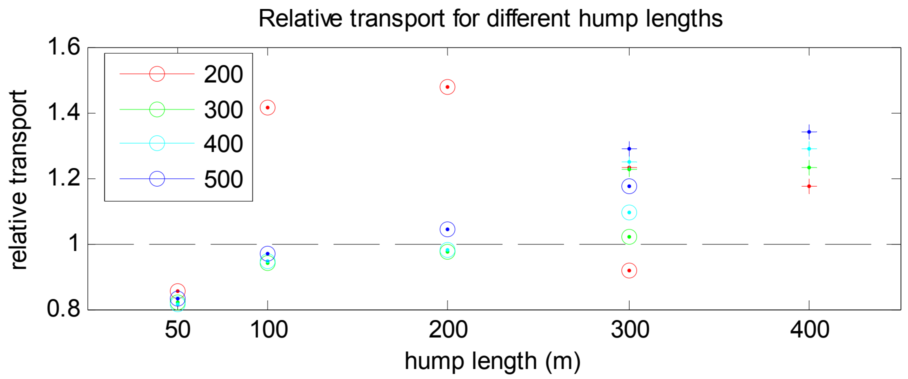


t = 9 hours

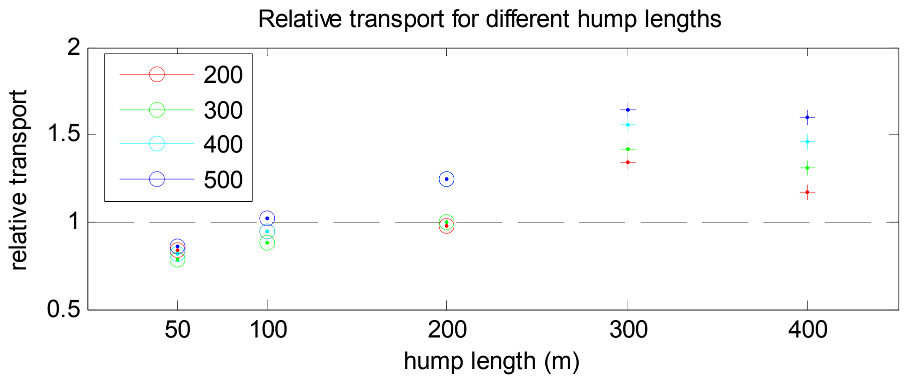


D.5 Sensitivity on depth of nourishment crest

Depth = 4 meter

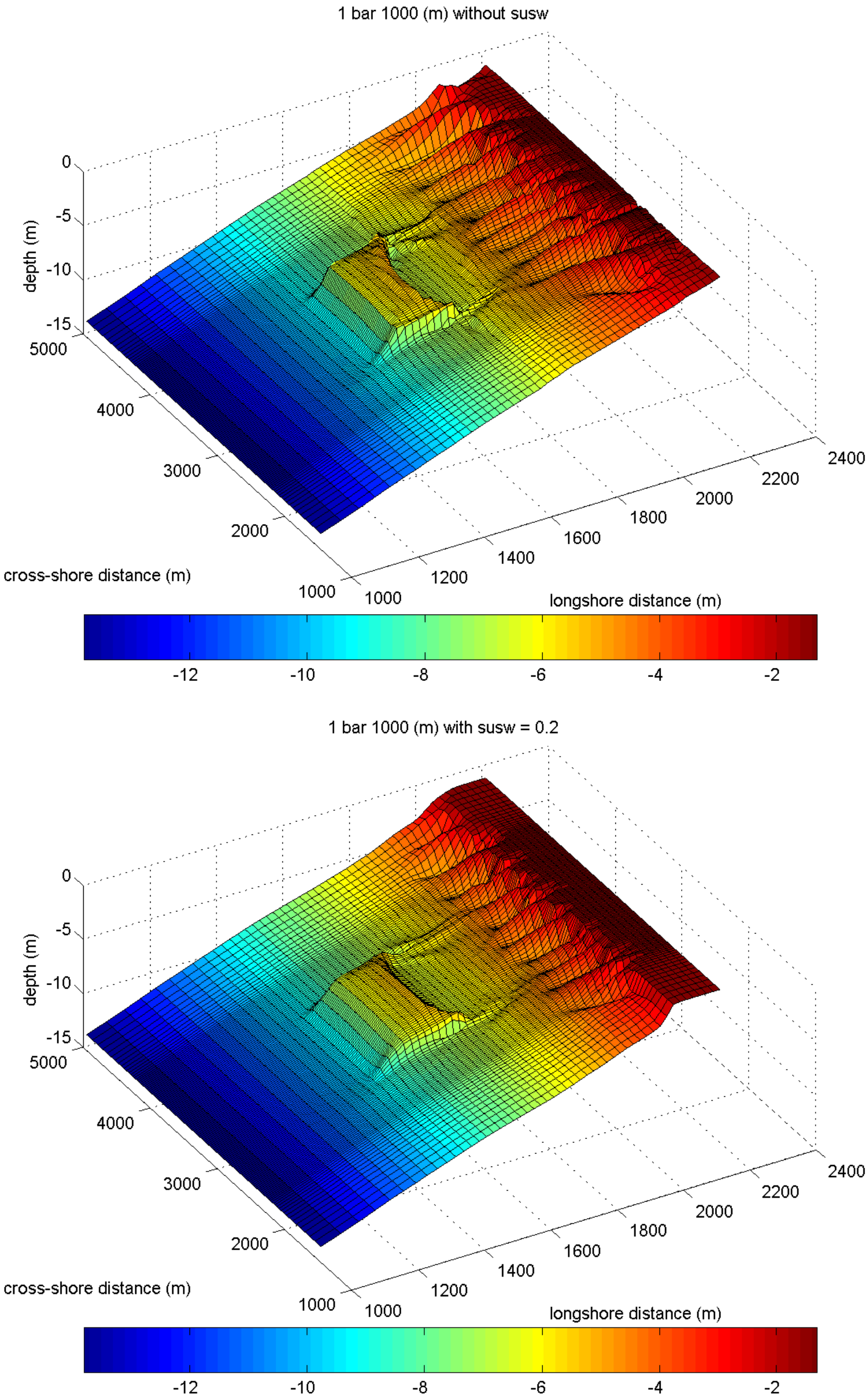


Depth = 3 meter



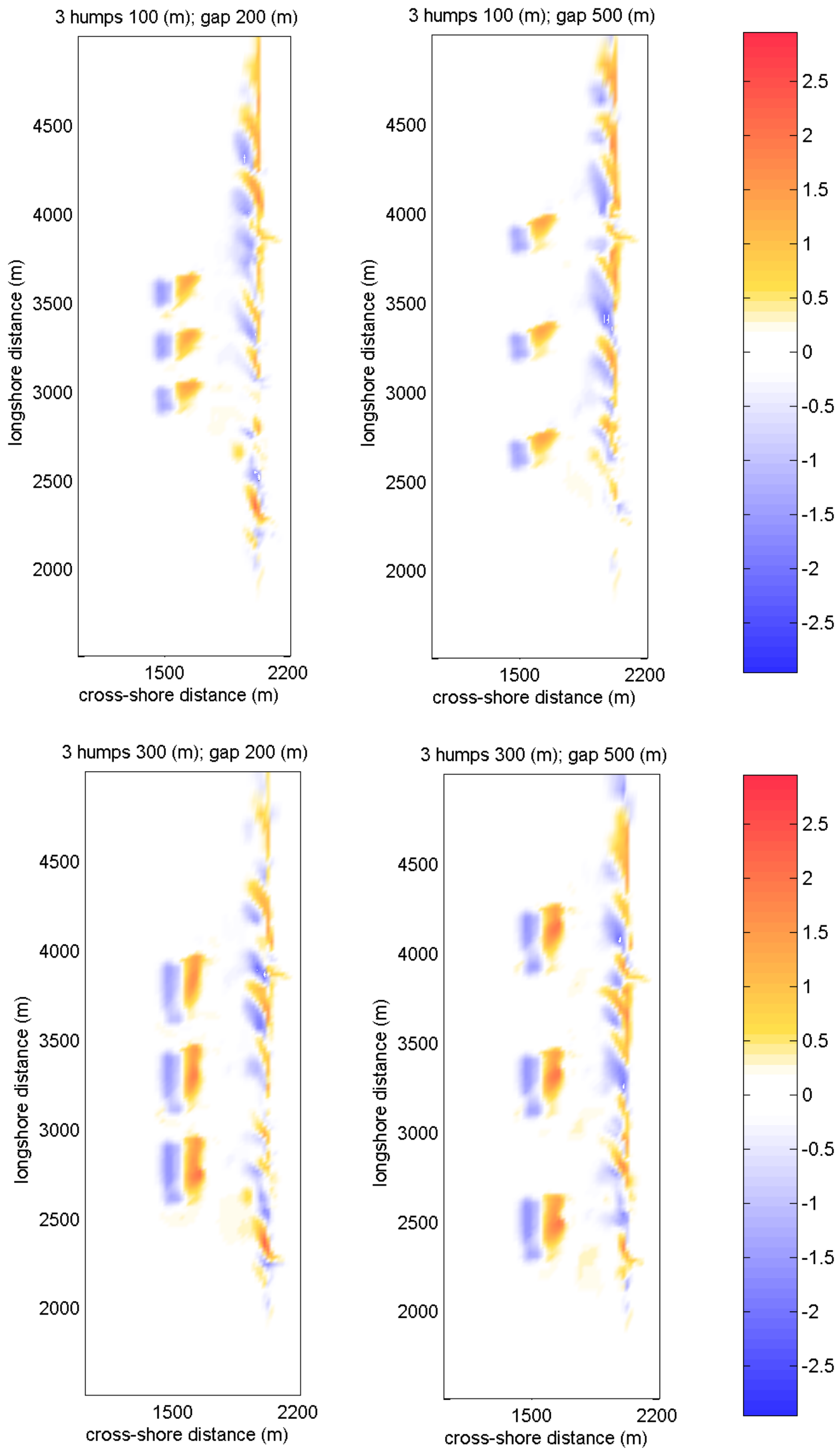
E Morphodynamic analysis

E.1 Influence of susw on bar behaviour



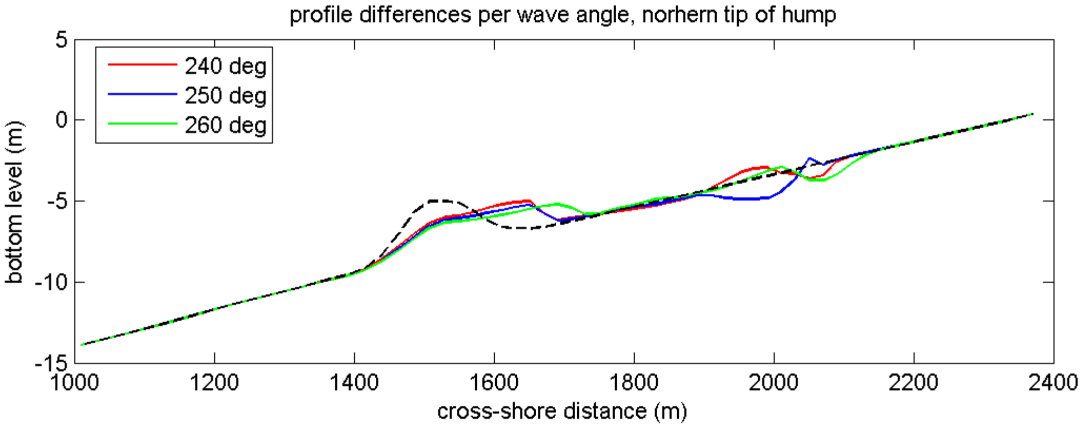
Bar nourishment after 42 days of morphodynamic simulating. Upper plot shows situation with susw = 0, lower plot shows the same for susw = 0,2

E.2 Gap width influence on morphodynamics (cumulative sedimentation and erosion)

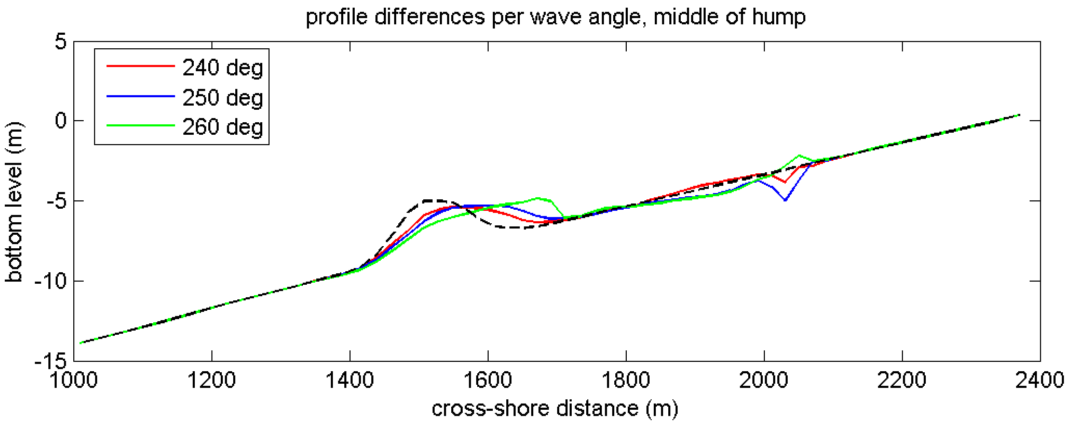


Cumulative sedimentation and erosion for humplike nourishing scenarios with 200 and 500 meter gap width

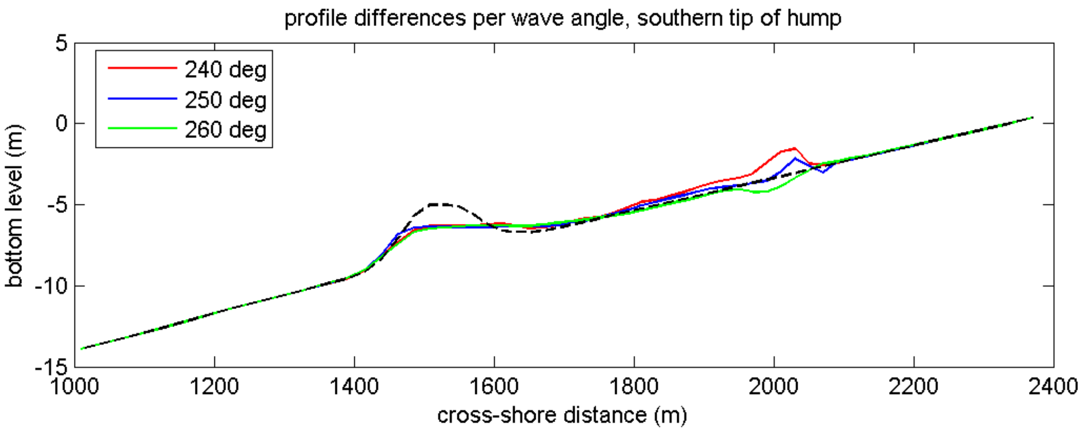
E.3 Wave angle influence on morphodynamics (2D bathymetry)



Comparison wave approach angles for 300 meter hump length and 500 meter gap width on northern tip

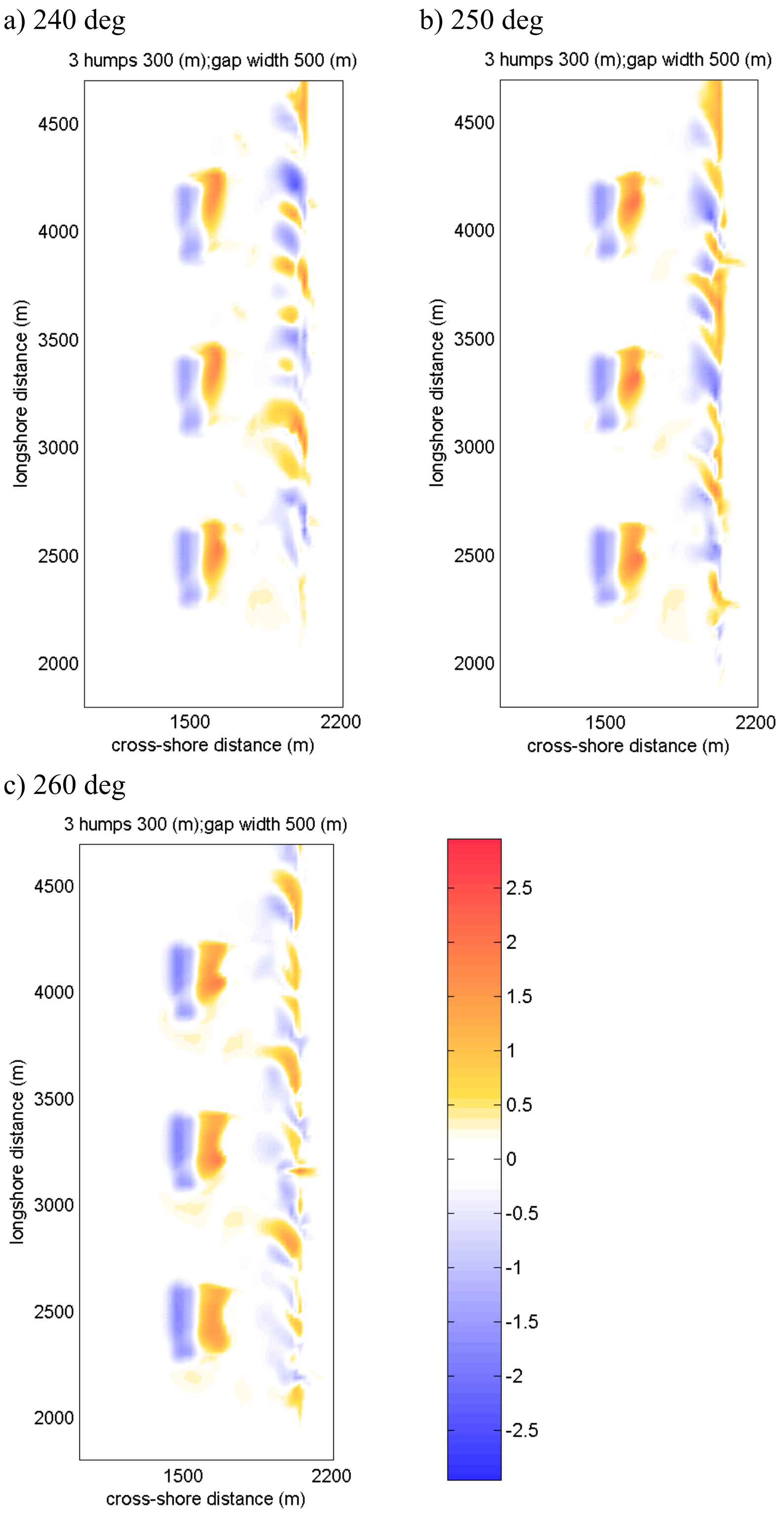


Comparison wave approach angles for 300 meter hump length and 500 meter gap width on middle of hump



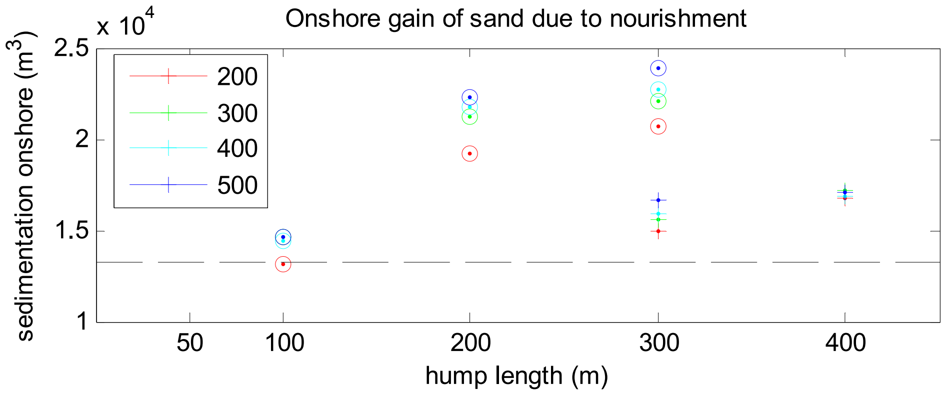
Comparison wave approach angles for 300 meter hump length and 500 meter gap width on southern tip

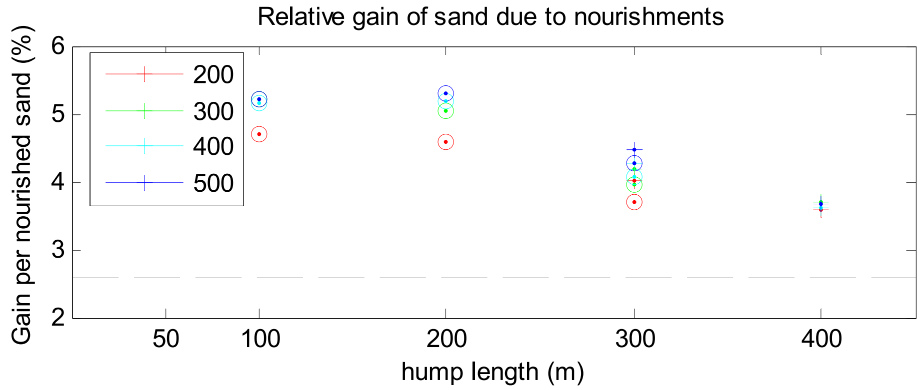
E.4 Wave angle influence on Morphodynamics (cumulative sedimentation and erosion)

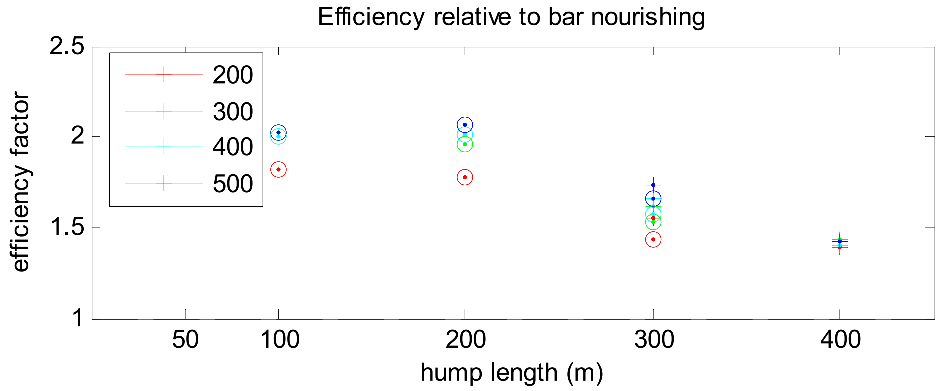


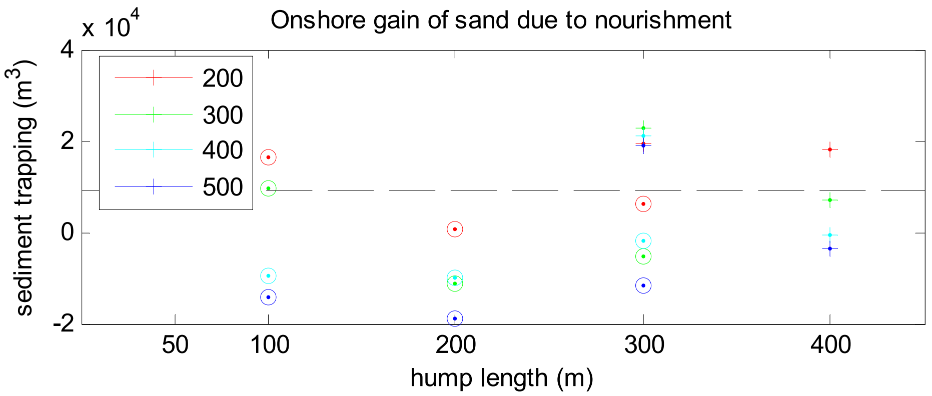
Cumulative sedimentation and erosion for 3 wave approach angles

E.5 Efficiency comparing for 240 wave approach

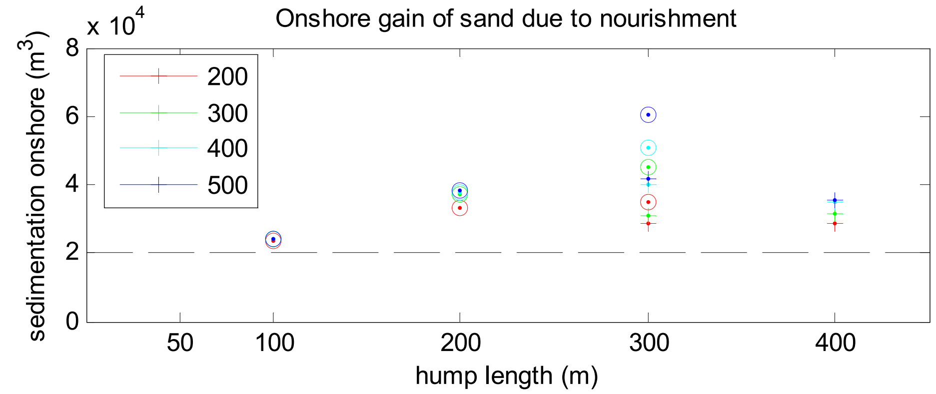


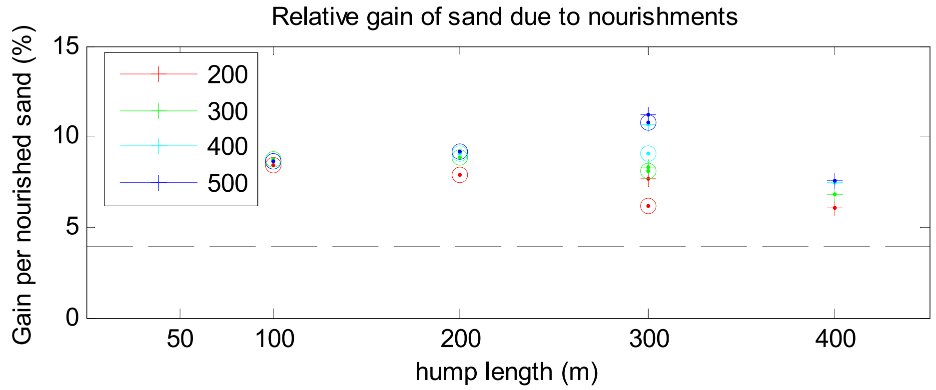


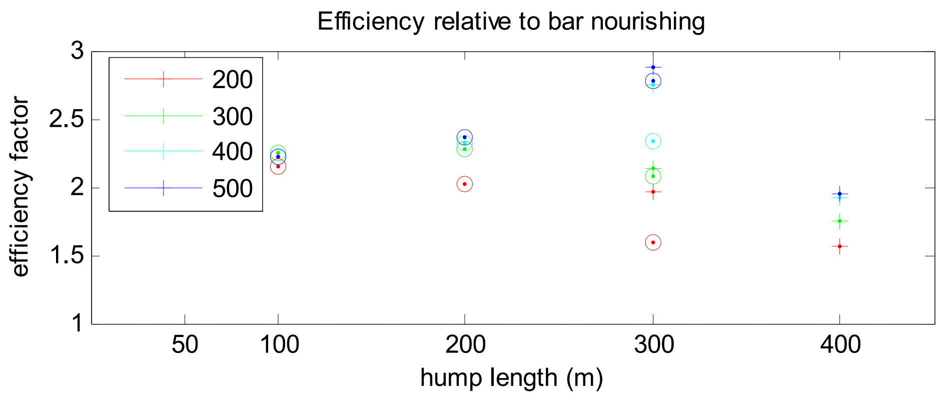


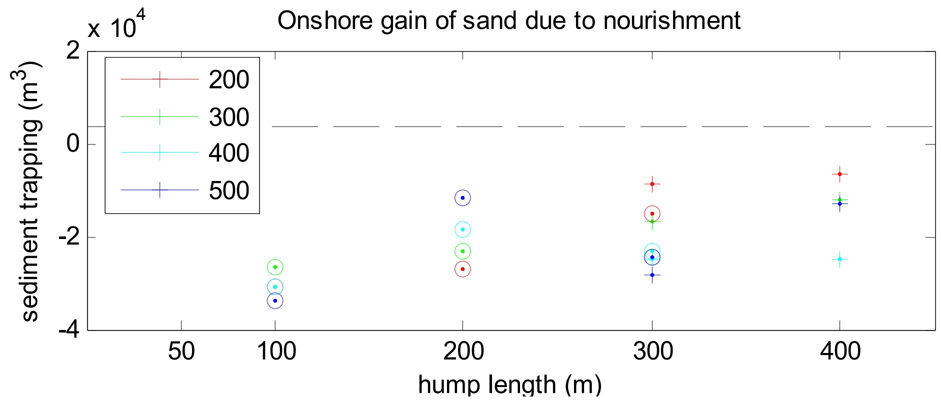


E.6 Efficiency comparing for 260 wave approach









E.7 Cumulative erosion and sedimentation for tidal analysis